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WAR DEPARTMENT

TECHNICAL MANUAL

NOTES ON PHYSIOLOGY IN AVIATION MEDICINE

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NOTES ON PHYSIOLOGY IN AVIATION MEDICINE

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SECTION I

EFFECTS OF PHYSICAL FACTORS

1. The sense of flight.—*a.* Flying requires the development of a new special sense, the sense of flight, which means the ability to react to the invisible movements of the atmosphere, the faculty to feel or sense conditions of the air and movements of the craft in flight, and to react properly with precise muscular contractions. The sense of flight is a composite sensation. It includes the feel of the seat, the feel of the controls, the sense of air pressure on the face and body, the action on the semicircular canals and vestibule of the ear, and visual, muscular, and visceral sensations. Probably the

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most important is the feel of the seat, and next important the feel of the controls.

b. The trained pilot is able to interpret certain sensations transmitted to his body where it comes in contact with his airplane in the air, and he reacts to these sensations reflexly. In this way he is almost able actually to anticipate movements of his craft, and he can at once, by coordinated control, compensate for and correct them. He is able to realize that his craft is almost to the point of losing its power of sustentation in a stall and in landing; he senses that he has acquired enough forward speed to execute certain maneuvers without consulting his instruments; and he knows to a great extent when he is beginning to slip or skid on turns. At the same time, he instantly infers subconsciously that changes in pressure required on the rudder bar and stick mean certain things and require certain actions.

c. Some students are never able to acquire this faculty, and presumably for that reason, are eliminated from flying training. The ability to acquire this sense of flight seems to be easier for the student who can readily relax physically and still remain alert mentally. While he is sitting stiff and rigid in his cockpit with a tense hold on his controls, he cannot acquire the "feel of the ship," as pilots express it.

2. New muscular controls.—*a.* In practically no other acquired accomplishment as flying are so many groups of antagonistic muscles held in a state of "static wakefulness." New combinations of arm and leg movements must be learned. For example, both feet are used in controlling the rudder; one hand moves the stick forward and backward as well as sidewise; one hand controls the throttle, spark, carbureter adjustment, and stabilizer. Accuracy and precision in flying requires a delicacy in coordinated movements of the stick and rudder, that is, coordination of muscular contractions of upper and lower extremities.

b. Students differ greatly in their ability to acquire these coordinations readily, if at all. This is a great factor in learning to fly. The serial reaction time machines are being used at present in an attempt to definitely determine a student's ability to coordinate arm and leg movements in a precise and alert manner. Age seems to be an important factor in acquiring the "sense of flight" and new muscular coordinations. Advancing age retards reaction time and impedes formation of new muscular responses.

3. Spatial orientation; instrument flying.—Under ordinary conditions, flying for the trained and skillful pilot becomes more or

less automatic. Although he makes the necessary corrections without conscious effort, he still relies on the information received through his senses as to changes he must make in the position of his airplane. How well his senses serve him and in what manner they are effective, if they suffice for him when he is lost in fog, the horizon gone, and the ground obscured, will be found in the subparagraphs below.

a. Man adjusts himself to his surroundings in a medium of time and space. He takes particular cognizance of his spatial adjustment and is constantly revising it as he acquires experience. Endowed with special organs of sense, he is usually able to maintain his relationship to other objects in space in a manner best suited to his present and urgent needs.

b. The prime faculties for space perception are vision, touch, hearing, and the kinesthetic sensations, the latter being sensations of movements received from muscles, tendons, and joints. Closely allied to the movements of the eye muscles and probably to the movements of all muscles of the body is the vestibular labyrinth, which constitutes part of each internal ear. It is concerned with the sensation of body weight and gravity and with the sensation of motion and direction of motion. In conjunction with the training of sight and touch, it aids in preserving a state of bodily equilibrium by regulating the movements of the body muscles and informing the brain of the position of the head.

c. A man with normal sense organs and vestibular labyrinths has little difficulty in orienting himself or maintaining his equilibrium upon the ground. Experience has taught him to correlate the position of his head and eyes. This takes place usually in an erect attitude. If he should reverse this attitude and view familiar objects while standing on his head, his visual impression would be unfamiliar and the factors of distance, size, and shape of these objects would seem erroneous.

d. When an erroneous preception exists, it is referred to as an illusion. An example is to place a blindfolded subject upon a board laid on the floor, with one hand resting on the head of a person standing in front of him. The board is now slowly raised a few inches while the person in front gradually lowers himself to his haunches. The subject feels that he is being lifted toward the ceiling and, when told to jump, his feet find the floor before he expects, and he falls in a heap. This happens because the normal accord between the visual and other sensory impulses produced by stimuli from external objects has been lost. When a condition arises in

which the usual coordination between sensory impulses is lacking, the brain tends to interpret the situation in the light of past experiences and in so doing creates a dilemma.

e. If the man on the ground is likely to form erroneous impressions due to a deviation from his usual attitude toward other objects in space, it is probable that the pilot, riding in a machine capable of all manner of evolutions, would be more easily subjected to false sense impressions. His sensory equipment is acted upon in a more radical manner and he utilizes it to a greater extent in order that he may maintain his proper spatial relationship and insure a condition of stability. As his experience develops, he can correctly interpret certain deviations and compensate for them, provided his sensory equipment allows for this.

f. The pilot relies principally for determination of his correct spatial relationship upon vision, which in point of range and delicacy surpasses any of the other senses. He maintains his relative position to the earth by viewing a horizon, either a true or a false one, between mist and sky, or by aid of the moon and stars. He gages distance from the ground, objects thereon, or from other airplanes by means of vision. Although he may ordinarily not be aware of it, he relies to some extent upon the sounds reaching his ears, changes in the rate of the motor, and singing of air through the struts. He also takes into automatic account changes in position of the airplane by the stimuli received upon the skin of his face and under his clothing from air currents and sensations of warmth and cold, and from the variable pressures on his buttocks and soles of his feet. In addition, the vestibular labyrinth is constantly effective in regulating the movements of eye and body muscles in response to changes in head position, thus aiding maintenance of balance.

g. If the prime factor for spatial adjustment, the visual, is eliminated, as it is in fog or absolute darkness, it is unreasonable to suppose that the auditory sense, dependent upon stimuli received from the airplane itself, will prove of any particular utility. The sensations received from variable air currents upon the body cannot be of sufficient informative value, especially if the pilot is encased in heavy clothing or in a closed cabin. The deeper sensations, derived from the stimulation of muscles, tendons, and joints, and the internal organs, although normally of great importance to the experienced pilot, are found by them to be unreliable when vision is obscured. It is the experience of pilots, when lost in a fog or darkness, that they are not aware of their relative position to the earth, and that they may emerge from a cloud in a spin, upside down, or in some

abnormal position. This fact would seem to indicate that the vestibular mechanism had proved inadequate in its role of preserving a state of balance. The mechanism of the vestibular labyrinths should be considered in order that some knowledge may be gained of the manner in which they function. They constitute part of each internal ear, the other part being the essential organ of hearing. They are embedded in a very dense bony capsule and surrounded by fluid. They also contain a fluid, the endolymph, which is capable of movement with various changes in head position. Each vestibular labyrinth consists of three membranous semicircular canals and two membranous sacs, the saccule and utricle, the latter receiving the openings from the semicircular canals. The canals are set in the three planes of space, horizontal, frontal, and sagittal, and are placed at right angles to one another. This structure enables them to receive stimulation in any position of the head. At one end of each canal near its opening into the utricle, is a dilated portion containing very delicate hair cells by means of which the nerve connections are obtained. The hair cells are roofed over by a membrane in the nature of a cupola which, when moved by the endolymph, impresses the hair cells and through them the nerve elements. The utricle in a certain portion also contains these hair cells and is acted upon in the same manner.

h. The accepted theory for the mechanism of stimulation of the semicircular canals is that with any movement of the head there is a lag from the inertia of the endolymph and the cupola in the particular canal which is lying in the plane of the movement. The movement of the cupola stimulates the hair cells so that a nerve impulse is sent out to the central nervous system to bring about a readjustment of the eyes, limbs, and body, to compensate for the new position of the head which initiated the movement. This response is rapid, but not lasting. However, the more slowly responding and similarly impressed mechanism within the utricles will maintain the new position. The semicircular canals might be called the dynamic organs of equilibrium because they respond to sudden movements or change in movement and bring about sudden readjustment of the eyes and limbs to counteract the movement of the head. The utricles seem to have a static function in that they respond to changes of position, elicit slowly, and preserve a readjustment of the eyes and limbs to counteract any movement of the head so long as the new position of the head is maintained.

i. The physiological action of semicircular canals and utricles is closely allied to the function of eye and body movement. The rela-

tionship to the eye movements may be demonstrated by turning a person at a certain speed about his own axis, in a rotating chair with his head in a position to affect, for example, the horizontal canals. To and fro motion of the eyes will result due to the transmittal of stimuli through the interrelated nerve tracts to the particular group of eye muscles involved. During this procedure, the person has experienced little disorientation.

j. If the person now keeps his eyes closed during similar rotation and after its cessation, he will experience the sensation of turning in the direction opposite to which the actual turning was done. During this maneuver, the endolymph in the canals of the plane of movement at first lags behind by its own inertia and provides a momentary sensation of turning in the correct direction. As turning continues, the endolymph moves at an equal rate; after turning ceases, it continues to move forward by its own impetus. This final action causes a sensation of turning in the opposite direction. Experience, through sight and muscle sense, has taught the person that when he turns in one direction and the endolymph lags behind, he is turning in that direction. When the endolymph continues to move after turning has ceased, he has a subjective sensation of turning in the opposite direction. This is explained by the fact that he interprets the lag of the endolymph to coincide with the proper direction of turning, but when turning has ceased and the head remains still, he experiences a relative movement of the endolymph in a direction opposite to himself and thus interprets the sensation. This is a subjective sensation of a disturbed relationship in space and is known as vertigo. The effect of semicircular canal stimulation upon bodily attitude can also be demonstrated. If similar rotation experiments are made with the subject's head, eyes closed, bent forward over his knees and if, after rotation has ceased the head is raised upright, a sensation of falling toward the direction of the turning will result and the trunk of the body will actually fall in that direction. During rotation, the endolymph has been influenced in the frontal plane which, when the head is raised, becomes at right angles to the floor, producing a sensation of falling in a frontal plane in the direction of rotation. This phenomenon is due to vertigo. Since the subject feels that he is turning in the opposite direction after rotation has ceased, he deliberately assumes the attitude of space where he conceives his body in a normal state of orientation ought to be. Because he feels that he is turning in a certain direction, he consciously leans toward the opposite direction in his effort at compensation. This is the direction of the initial rotation; but since there is no rotation, the body natu-

rally falls toward that direction. Turning in a frontal plane is actually a matter of doing cart wheels and the result is a sensation of falling in the frontal plane to the right or left. Turning in a sagittal plane is a matter of doing somersaults and produces a sensation of falling either backward or forward. Horizontal plane rotation causes a sensation of movement about one's own axis, either to the right or left.

k. Although these reactions can be elicited in a revolving chair, the question arises whether or not the movements of an airplane can be rendered sufficiently violent to evoke similar disturbances of equilibrium. Perhaps an exact parallel cannot be made, but, there exists in both cases a distinct and positive action upon the endolymph in the vestibular labyrinths. In the airplane, it is probable that the brief time when it has straightened out from some rotatory evolution is the critical period. During a spin, for example, with the head in the ordinary position and the gaze fixed upon the ground, the rotation takes place in a frontal plane which is parallel to the earth; but when the machine comes out of the spin and flies on a level keel, if the attitude of the head relative to the body remains unaltered, the frontal plane becomes at right angles to the ground and the resulting vertigo, if experienced, will be an effect of falling to the right or left. However, when the pilot knows his relative position in relation to the ground, he can compensate for the expected vertigo by holding his head in the same relative position to the ground as during the spin and so avoid the momentary initiation and final effects of the vertigo. The vertigo after rotation in the chair can be materially reduced by fixing the gaze. It would seem that the same results could be obtained in a rotating airplane. If, however, a pilot is flying in a fog or darkness with his position relative to the ground obscured, he knows only his relative position to the unstable airplane and is lost insofar as other objects in space are concerned.

l. It was formerly believed that properly functioning semicircular canals, with intact afferent paths to the higher centers, were essential for correct spatial orientation in flying and that an adequately trained pilot could fly by instinct in fog or snow. This has been disproved in experimentation with instrument flying. In these experiments, the subject pilot flew under a hood, without external visual reference, and accompanied by a safety pilot. All these flights terminated in a tight spiral to right or left, forward progression hopeless, and in many cases ending in spins. This occurred at the very longest within 20 minutes after beginning the test.

m. The pilot's auditory, tactile, and kinesthic sensations have been found inadequate to give him proper spatial adjustment and his vestibular labyrinths, when vision is blocked, have failed to maintain proper equilibrium and orientation. Therefore, when he is unable to utilize those most important distance receptors, the eyes, he is in a quandary and finds his position to the earth entirely at variance with his preconceived impression.

n. Fortunately the pilot does not need to rely entirely on the interpretation from his own senses in fog or darkness, although he may be prone to make use of these inherent abilities which have directed his movements upon the ground during his lifetime and even after he has taken to the air. Airplanes have been equipped with instruments which, if properly used, should enable the pilot to fly under conditions which prevent his seeing the ground and deprive him of points of reference for determining the position of his airplane. Flying under such conditions, however, requires training and the pilot must learn to rely on and use his instruments. The importance of training in instrument flying has been fully recognized and the pilot must be familiar with their use. As time goes on, the trained pilot has learned to rely upon the story told him by his instruments, especially when "flying blind." Accurate instruments have contributed immeasurably to the safety of aviation throughout the past years.

4. Sensitiveness to motion.—The undulatory and rotary motions of flying may cause vertigo, nausea, or vomiting. This is often true of the novice. The relation of the effects on the eyes, ears, and viscera to these disturbances constitutes a physiological problem. Why some students overcome them and others do not is still an unanswered question. Some, even after they have become accomplished pilots, are not entirely able to withstand rapid spiral motions. This sensitiveness to motion apparently is always more pronounced in the passenger than in the pilot who is actually controlling the airplane. The position or location of the cockpit evidently has something to do with nausea and vertigo in spirals and turns, being more pronounced in the rear cockpit or in the rear of the cabin of a transport. Attention or occupation seems to influence this sensitiveness, as many a pilot is more affected by maneuvering when he relinquishes the controls to the occupant of the rear cockpit.

5. Effect of speed and centrifugal force.—*a.* A speed in excess of 425 miles per hour has been attained. In straight-away flying, speed in flight probably has no other effect than that of a terrific blast of air. While traveling at such a tremendous rate of speed,

the flyer does not dare expose parts of his body to such terrific pressure. If he held out an arm it would probably be broken, or if he stood up in his cockpit his head would probably be snapped backward with such force that his neck would be broken.

b. The real danger in tremendous speed, however, is in banks and turns, and is due to centrifugal force. As the flier makes a bank and turns abruptly from his original line of flight, the "pull" of centrifugal force acts in the direction of his original line of flight; that is, away from his head and toward his feet. The result is that the blood is literally thrown away from the brain, causing cerebral anemia or a faint. Recovery promptly follows when the circulation adapts itself as the centrifugal force changes to the new direction of flight. This phenomenon is often noticed by pilots flying in races and also in pulling out of fast dives abruptly. The tendency toward fainting on turns and pulling out of dives varies greatly with individuals. Some state emphatically that they have never experienced such a sensation. It seems to vary at times in one individual, and possibly depends to some extent upon his general physical condition. One pilot described the sensation he experienced in pulling out of a dive as follows: "Suddenly spots appeared before my eyes and then everything went blank for an instant, probably 1 or 2 seconds, judging from the altitude I had gained."

c. The condition which actually occurs is an accumulation of blood, driven from the head, in the splanchnic area. This is evidenced by pilots' statements that they are able to anticipate and forestall or prevent this sudden faint by "bearing down"; that is, pressing against the safety belt and increasing the intra-abdominal pressure. Many pursuit pilots, in pulling out of dives and in other combat maneuvers, accomplish this by yelling at the top of their voices. Wearing a broad and tightly buckled belt probably would aid materially in preventing a faint.

d. The actual limit of speed, with abrupt changes in direction, that may be attained by man is not known, but it seems possible that a speed may be attained which, when a turn is made, would be sufficient to cause pressure on the brain stem in such a manner as to cause death. Experiments have been and are being made in spinning dogs on a wheel, to all intents and purposes centrifuging them. Some of these showed injury to the brain resulting from its being violently pressed against the skull. Thus, in addition to the effects of cerebral anemia, there may be trauma of brain substance in turns at tremendously high speeds; higher than have yet been attained, however.

6. Effect of cold.—*a.* Flights to high altitudes expose the body to sudden and extreme changes in temperature which call for bodily compensations of unusual degree and promptness. The average atmospheric temperature decreases with increase in altitude, slowly near the earth, and more rapidly as the altitude increases.

b. The temperature during the first mile drops 1° F. in every 540 feet of ascent; from 14,000 to 16,000 feet it drops 1° every 360 feet of ascent; from 23,000 to 29,500 feet it drops 1° for every 188 feet of ascent. From about 32,500 to 39,500 and above, the temperature remains quite constant at approximately 62° below in summer and 71° below in winter.

c. The intensity of cold experienced in flying varies with the season and the height attained. It is accentuated by speed and increases by stages. There occurs first a sensation of chilling, followed by the reaction of "goose pimples" and pallor of the skin. If the aviator has sufficient protection, the reaction stops here; otherwise, chilling is more accentuated. There is stiffness of the extremities, numbness, and finally a tendency to sleep. This fall of temperature stimulates body metabolism, thereby increasing the demand for oxygen. However, the available supply of oxygen decreases as altitude increases.

d. Heat production is varied by increasing or decreasing physiological oxidation of foodstuffs such as carbohydrates, fats, and proteins. It is voluntarily controlled to some extent by ingestion of food and by muscular exercise which are attended by a marked liberation of heat. Heat production, however, is mainly under involuntary control through special centers controlling muscular metabolism. Under the influence of extreme cold, increased oxidation occurs, which is augmented by muscular contractions (shivering).

e. Heat loss from the body is governed by the excreta (small percentage), by expired air, by evaporation (depending on humidity and temperature), and by conduction and radiation. The latter two vary greatly with conditions; high external heat tends to diminish loss by radiation and increase loss by evaporation. In cold weather the body is augmented by the use of clothing, thus diminishing greatly the loss by evaporation and radiation. Heat loss is controlled mainly by reflex control through vasomotor nerves and nerves controlling perspiration. The amount of blood brought to or in contact with the skin, where it loses its heat by conduction and radiation to the outside air, is diminished; also the amount of sweat poured out upon the skin is decreased, thus diminishing or stopping altogether loss by evaporation. For example, when cold air strikes the skin it stimulates part of the vasomotor center, which controls the vaso-

motor fibres of the skin, thus causing a constriction of the arterioles at or near the skin surfaces and producing less exposure of blood and a consequent heat conservation.

f. Young men possess rapid and adequate reactions to cold, while older men, with less power of response, are far more sensitive to low temperatures.

g. While flying, frostbites may be prevented by smearing the face and hands with vaseline or cold cream. For protection against cold, two garments are better than one, even though the total thickness is less than one heavy piece. Clothing should not fit tightly and there should be no orifices through which outside air can penetrate. Winter flying suits should be made so they can be adjusted snugly at the collar, wrists, and ankles.

h. As a service type airplane can attain its ceiling in 1 hour's time, pilots may be exposed to relatively rapid and extreme changes in temperature. There is little provision for protection against the cold other than clothing in military aviation where open cockpit airplanes are often used, although some flying suits have been designed to be heated electrically. Cabin-type ships have two methods of heating. One method uses heat collected from around the exhaust and conducted to the cabin. This may be dangerous if there is a leakage of carbon monoxide, and the tendency is to do away with this type. Another method is to heat the cabin by means of steam heaters which derive their source of heat from a small tank of hot water heated by the exhaust. This is the better method from the standpoint of safety.

7. Effect of wind.—*a.* In flying, the aviator passes from a state of comparative calm to a motion through space that has the effect of a gale. This terrific blast accentuates the cold. A breeze of 15 miles per hour at a temperature of 59° to 68° F. will increase metabolism 19 percent. This action is present in flying and the increase in metabolism calls for an increase in oxygen demand.

b. A strong wind causes irregularity in the depth and rate of breathing, but generally lung ventilation is favored. As a result, the alveolar tension of carbon dioxide is decreased and that of oxygen increased in the lungs. This phenomenon, more distinct and constant at great heights, results in a decrease of blood CO_2 and a consequent state of acapnia. This is not wholly true in the modern airplane with ample windshield, as the pilot's face is exposed only to the blast for short intervals when he looks over the side or around the windshield.

8. Influence of light.—*a.* Although light is considered healthful, it is certain that man and animals can live a long time in darkness without any noticeably bad results. Light, however, does have a

physiologic influence. In general, the shorter the wavelength the greater the physiologic effect. The spectrum of sunlight reaches only 290 microns in ultraviolet light, and light waves less than 300 microns produce in all living cells a strong and often harmful reaction. Bacteria begin to die quickly at wavelengths of 296 microns or shorter.

b. The effect of light is probably due to the photochemical reactions produced when light energy is absorbed, but the exact nature of this reaction is unknown. Cell death from ultraviolet light is due to a change in the protoplasm, which so sensitizes the proteins to heat that they coagulate at low temperatures. Ultraviolet light renders protein solutions less soluble, this being indicated by their easier precipitation.

c. Snow blindness and sunburn depend on the reflection of ultraviolet rays from large areas of water, snow fields, and desert areas. These short rays are absorbed by the cornea, conjunctiva, and skin, and injure their respective protein constituents. Any radiation of a wavelength less than 295 microns will produce harmful effects. Sunburn may be prevented by the application of cold cream to the exposed portions of the body before flight. Snow blindness should be guarded against by wearing approved tinted goggles. The wearing of such goggles should be compulsory in flying over water, at flying fields where the terrain is covered with snow or where glaring sunlight predominates.

d. That light stimulates metabolism is shown by the amount of carbon dioxide expired. Breathing is changed in rate and depth. Light stimulates the rate of growth.

SECTION II

MECHANICS OF RESPIRATION

9. Definition.—*a.* Respiration is the function by which air is drawn into and expelled from the lungs. In a physiological sense,

it refers to the gaseous exchange between an organism and its environment.

b. Under normal environmental conditions, man breathes only atmospheric air. This has a composition of essential gaseous elements which exist in unvarying volumes percent under varying amounts of barometric pressure.

c. There are two processes by which respiration is accomplished; external respiration, or the gaseous exchange between the air in the alveoli of the lungs and the pulmonary capillaries and internal respiration, or the interchange between the blood and the tissue elements.

d. The necessary and constant renewal of air in the lungs is made possible primarily by movements of the thorax and constitutes normal breathing.

10. Inspiration.—Inspiration is effected by means of movements derived from four distinct mechanisms, as follows:

a. The thoracic lid or operculum, which is composed of the first pair of ribs and the manubrium sterni. Its upward and forward movement increases the anteroposterior diameter of the thorax, thus expanding the anterior portion of the lung apex.

b. The upper costal series, or the second, third, fourth, fifth, and sixth ribs. Except for the second, these ribs assume a more horizontal position during inspiration and thrust the sternum forward and upward. These movements, effected by the external intercostal muscles, increase the anteroposterior diameter of the thorax. Elevation of the bowed midportion of each rib from second to sixth increases the transverse thoracic diameter.

c. The lower costal series and the diaphragm. During inspiration, the ribs from seventh to tenth swing outward and upward, thus producing a widening of the subcostal angle and an increase in the transverse diameter of the lower part of the thorax. There is a slight reduction of the anteroposterior diameter. The diaphragm, chief muscle of respiration, has a surface of about 270 square cm. Its range of movement varies from 1.2 cm. in quiet breathing to about 3 cm. in forced breathing. A descent of 1 cm. will increase the capacity of the thorax by 270 cc. and produce a corresponding increase in air volume in the lungs. The combined action of the diaphragm by means of its costosternal and crural portions is to enlarge the anteroposterior diameter of the thorax and to increase its vertical diameter. It is almost sufficient alone to carry on quiet respiration.

d. The floating ribs and abdominal muscles. The eleventh and twelfth ribs and the recti and oblique muscles of the abdomen act

in accord as antagonists of the diaphragm. The muscles relax as the diaphragm descends and contract with its ascent.

11. Expiration.—Expiration is chiefly a passive act, especially during quiet breathing. When inspiration has ceased, the stretched tissues of the lungs contract by virtue of their own elasticity, thus causing the thorax to sink by its own weight and by the elastic recoil of the stretched costal cartilages. During forced expiration, the size of the thoracic cavity is further reduced by the ascent of the diaphragm caused by subatmospheric pressure within the cavity, increased intra-abdominal pressure from contracted abdominal muscles, and depression of the ribs from contraction of the internal intercostal muscles.

12. Accessory aids.—Accessory respiratory movements are controlled by the sterno-mastoid, trapezius, scaleni, rhomboids, pectorals, and serratus anticus. These muscles are brought into play when inspiratory effort becomes more forcible due to muscular exertion or some other cause. The muscles which control the opening of the external nares and the size of the glottis, also act in an accessory capacity by reducing the inflow of air.

13. Respiratory air.—*a.* The volume of air breathed varies with many bodily conditions such as sitting, walking, sleeping, age, emotions, etc. However, in normally quiet breathing, the amount of air breathed in or out of the lungs with each respiration averages about 350 to 500 cc. This is the tidal air. After a normal respiration, a maximum expiratory effort will expel 1,500 cc. of additional air. This is the supplemental air. A maximum inspiratory effort following quiet respiration will add an average of 1,500 cc. more air to that in the lungs. This is the complemental air. If tidal air, supplemental air, and complemental air are added together, the individual vital capacity will be obtained. This averages about 3,500 cc. for the adult man and is the maximum amount of air which can be expired after a maximum inspiration. It is about eight times as great as the normal-size breath and obviously depends on the size of the individual and the functioning of his respiratory apparatus. It has been shown that there was a consistent relationship between vital capacity and surface area of the body.

b. After a maximum expiration is made, there will be about 1,000 to 1,500 cc. of air remaining in the lungs. This is the residual air. If residual air and supplemental air only are considered, it is that which is in the depths of the lungs in more or less contact with the respiratory epithelium. This is the alveolar air. It is actually a physiological entity because it serves the purpose of carrying out

gaseous interchanges with the blood. It amounts to about 3,000 cc. Adjustments in breathing render the alveolar air fairly constant.

c. There is also a dead air space found in the air passages, nasopharynx, trachea, and bronchi, which amounts to 150 cc.

14. Intrapulmonic pressure.—*a.* The air passages and alveoli of the lungs are in direct communication with the external air. Therefore the pressure in these cavities at rest is equal to that of an atmosphere. During inspiration, however, the intrapulmonic pressure falls temporarily below that of an atmosphere, the amount of fall depending on the depth and rapidity of inspiration and size of the opening. In conditions such as coryza, bronchial asthma, pathology of the bronchial tree, etc., the pressure decrease below the constriction will be magnified during inspiration. Such a consideration would appear to be of importance in connection with aeration of the lungs in aviation.

b. During expiration, there is a temporary rise of intrapulmonic pressure. This is due to the sinking of the chest wall and a consequent compression of the escaping air. Intensity of the respiratory movement and the size of the external openings also affect this pressure. It is increased, for example, in coughing when the glottis is closed.

c. While quiet inspiration is in progress, the fall of intrapulmonic pressure equals -9 or -10 mm. of water. During quiet expiration, the rise of intrapulmonic pressure equals 7 or 8 mm. of water. It is possible with the glottis firmly closed to lower this pressure 30 to 80 mm. of mercury by means of a strong inspiration and to raise it 60 to 100 mm. of mercury by a strong expiration. If 760 mm. of mercury are assumed as the atmospheric pressure, the intrapulmonic pressures during normal breathing will be the same (760 mm. of mercury) at the end of inspiration and expiration.

d. Every marked variation in intrapulmonic pressure greatly influences the flow of blood to the heart.

15. Intrathoracic pressure.—*a.* There is a pressure maintained within the pleural cavity and mediastinal spaces known as the intrathoracic pressure. Normally this is always negative or less than an atmosphere. It is, in substance, the intrapulmonic pressure minus the elastic pull of the lungs. Since the intrapulmonic pressure during quiet breathing equals an atmosphere, the intrathoracic pressure will be less than an atmosphere by an amount which depends on the force of lung recoil. The deeper the inspiration, the more negative will the intrathoracic pressure become.

b. It has been estimated that the intrathoracic pressure at the end of quiet inspiration equals −7.5 mm. of mercury and at the end of expiration equals −4.5 mm. of mercury. Therefore, during respiration, this pressure varies 3 mm. of mercury. Again assuming an atmospheric pressure of 760 mm. of mercury, the intrathoracic pressure at the end of inspiration will be 752.5 mm. of mercury and at the end of expiration will be 755.5 mm. of mercury.

c. These negative pressures, which exist in the thoracic cavity during the act of respiration, affect the organs in the mediastinal space. Their chief action is exerted upon the flow of lymph and blood, especially the latter. For example, the large veins of neck and axillae are under the pressure of an atmosphere exerted through the skin; also, the inferior vena cava in the abdomen. The superior and inferior vena cavae and the right auricle are under a pressure of less than an atmosphere. The difference in these pressures will tend to favor the flow of blood to the heart by means of a sucking action during inspiration. Intra-abdominal pressure will augment this effect on the inferior vena cava. The arrangement of valves in the subclavian, femoral, and jugular veins will enhance the aspiratory action.

d. Although it would seem that an opposite effect could be produced on the arteries of the body, this probably does not occur because of the thickness of their walls and their high internal pressures. However, in the pulmonary circuit the blood flow from the right to the left side of the heart is favored by changes in the intrathoracic pressure.

16. Nervous control.—The respiratory movements are regulated and rhythmic under normal conditions. The muscles involved in breathing are thrown into action by the intermediation of nerves derived from motor cells situated at various levels in the medulla and spinal cord. For example, the facial nerve controls the muscles of the alae nasi, the cervical and brachial nerves the muscles of the neck, the phrenic nerve the diaphragm, and the thoracic nerves the intercostal muscles. The activities of these nerves and their groups of cells must be correlated among themselves according to the needs of the organism.

17. Respiratory centers.—*a.* It has been shown by experiment that this correlation exists by reason of certain specialized portions of the central nervous system which are the receiving centers for afferent stimuli from the lungs and other parts of the body and which are sensitive to changes in blood composition. These special-

ized portions are known as the respiratory centers and are located in the medulla oblongata.

b. The experiments tended to demonstrate that the central respiratory mechanism (in the cat) is made up of four parts:

(1) That part at the level of the striae acusticae which sends out impulses, causing a series of prolonged inspirations and giving respiratory tone.

(2) That which may or may not be located in the same region as the inspiratory center but which causes contraction of expiratory muscles.

(3) That in the upper pons which controls both the inspiratory and expiratory centers, producing respirations of the normal type.

(4) That below the striae acusticae which, when working alone, causes gasping respiration.

c. The respiratory center as a whole is essentially automatic and probably possesses an intrinsic rhythmical activity resembling that of the heart.

d. Observation shows that stimulation of any of the sensory nerves of the body may affect the rate or amplitude of the respiratory movements. For example, stimulation of the cutaneous nerves by a dash of cold water obviously affects respiration. Stimulation through the nerves of sight and hearing and even emotional states produces noticeable changes. It can be assumed, therefore, that the respiratory centers possibly have a connection with the sensory fibers of all the cranial and spinal nerves.

e. When a sensory nerve trunk is stimulated experimentally, one of two effects may be produced; either quicker, stronger inspiration and active expiration or an inhibition of respiration manifested by cessation or slowing. These results tend to show that there are sensory fibers which have a stimulating action and those which have an inhibiting action, or respiratory pressor and depressor fibers, respectively.

f. The sensory fibers, which are distributed along the respiratory passages themselves, have a specially important connection with the center. The vagus nerves, which serve to maintain a tonic action and a normal rhythm of respiration, clearly demonstrate this relationship. If the vagi are severed, breathing will become much slower and of greater amplitude, demonstrating the removal of some factor which normally keeps the respiratory movements at a more rapid rate. This factor is the constant action of these nerve fibers upon the respiratory center.

g. If the severed ends of the vagi are stimulated experimentally, breathing will be affected in various ways, depending on the strength of the stimulus and the condition of the center. The substance of these experiments has been to demonstrate that the vagus probably has two kinds of fibers which act normally on the respiratory center; the inspiratory fibers, to increase the inspiratory discharge from the center and the expiratory fibers, to inhibit inspiratory discharges partially or completely.

18. Hering-Breuer reflex.—The manner in which the sensory fibers of the vagus are stimulated normally was considered by Hering and Breuer to be caused by the alternate expansion and collapse of the lungs. The immediate cause of the arrest of inspiration during ordinary breathing is the distension of the lungs to a certain point and a consequent inhibitory stimulus transmitted up the vagi to the respiratory center. Also, as a complementary phase, a certain collapse of the lungs stimulates another set of fibers that initiates inspiration. These reflex inhibitions and stimulations of the respiratory center are known as the Hering-Breuer phenomenon. It is believed to be essentially correct.

19. Carotid sinus.—In connection with the nervous control of breathing, the action of the carotid sinus, a dilatation which is normally present at the bifurcation of the common carotid artery, is noted. At this point, the artery wall is thinner than that of the adjacents parts and has numerous sensory receptors lying in the deeper part of its adventitia. The nerve, which leaves the sinus, joins the glossopharyngeal and may make connections with the vagus and perhaps the superior cervical ganglion and the hypoglossal nerve. When the afferent fibers of the carotid sinus are stimulated, there arises a reflex excitation or inhibition of the respiratory center, depending on the strength of the stimulus. A rise of blood pressure at the carotid sinus causes inhibition of respiration and a fall of blood pressure produces quickened respiration. Respiratory rate, heart rate, and blood pressure may therefore be regulated by the sensory receptors in this sinus. Although some observers believe that the effects obtained by vagus stimulation are due to excitation of afferent fibers from the carotid sinus rather than the lungs, others, while acknowledging this action, insist that afferent fibers from the lungs have a similar action.

20. Other nerves.—*a.* Other sensory fibers to be considered in relation to the respiratory center are those from the superior laryngeal nerve which supplies the mucous membrane of the larynx, and those from the glossopharyngeal nerve which supplies the pharynx.

Stimulation of these fibers produces an inhibition of respiration; that is, the chest comes to rest in a position of passive expiration. Also, the sensory fibers of the trigeminal nerve to the nasal mucous membrane cause a similar inhibition. The effects so produced are protective against injurious substances, such as gases, and serve to minimize the irritability of the respiratory center.

b. It was stated that the respiratory center is ordinarily automatic and rhythmic in action. However, for short periods of time, it may be completely under voluntary control. The excitation or inhibition of respiration, whether caused by sensory stimulation or voluntary interference, would appear to be protective in various ways or preparatory to some particular effort. These disturbances, therefore, effect the main regulation of breathing only on occasions.

SECTION III

CHEMISTRY OF RESPIRATION

21. General.—*a.* In addition to the reflex control of respiration, there are equally important chemical factors of control. The normal rate and depth of breathing is an expression of the balance between reflex and chemical stimuli. Each one so influences the other that they cannot be considered as separate entities.

b. The chemical control of respiration is dependent upon the composition of the blood supplying the respiratory center and has its foundation upon the interchange of gases between the tissue cells and the surrounding fluid, and interchange of gases between the circulating fluid and the external medium, the air.

22. Atmospheric air.—In order that the chemistry of respiration may be studied, the initial basis is derived from a consideration of the atmospheric air.

a. Atmospheric air consists of three constituents from a physiological standpoint: oxygen, nitrogen, and carbon dioxide. Although other gases, such as argon, neon, krypton, helium, etc., are present, they may be considered inert.

b. The mixture of oxygen, nitrogen, and carbon dioxide in air is markedly uniform. If a specimen be taken from midocean, sea level, or mountaintop, the percentage of these gases by volume averages the same: oxygen, 20.96; nitrogen, 79; carbon dioxide, 0.04.

23. Laws of gases.—Atmospheric gases, like other gases, are subject to certain laws, which may be stated as follows:

a. At constant temperature, the volume occupied by a gas is inversely proportional to the pressure.

b. At constant pressure, the volume of a gas is proportional to the absolute temperature, where 0° C. is 273° on the absolute temperature scale.

c. The partial pressure or tension of a gas, in a mixture of gases having no action on one another, is equal to that which the particular gas would exert if it alone takes up the space occupied by the mixture; that is, in a mixture of gases at a certain pressure, the pressure is divided between the different gases in proportion to their relative volumes.

d. The amount of gas going into solution in a liquid which has no chemical attraction for the gas depends on its solubility and is proportional to the partial pressure of the gas.

24. Diffusion.—When one of these gases is exposed to a chemically inert liquid at a given pressure and temperature for a sufficient length of time, the molecules of the gas will pass into the liquid until equilibrium is reached. For example, when water is exposed to a pressure of CO_2 of 40 mm. Hg, the tension of the gas in solu-

tion will become the same as the tension of the gas outside; that is, 40 mm. Hg. If the pressure of CO_2 outside is now raised to 46 mm. Hg, more gas will pass into solution to effect an equilibrium in tension. Also, if the pressure of CO_2 outside is lowered to 35 mm. Hg, gas will leave the solution until equilibrium is established. Therefore, the greater the pressure the larger will be the amount of gas taken up by the liquid at a given temperature. When, however, the temperature is raised, less gas will be taken up by the liquid for a given pressure.

25. Absorption coefficient.—The absorption coefficient of a liquid for a gas at a given temperature is expressed by the number of cubic centimeters of gas measured at normal temperature and pressure (0° C. and 760 mm. Hg), which will be taken up at the particular temperature by 1 cc. of the liquid when the gas is at a pressure of 760 mm. Hg.

26. Solubility.—*a.* Two gases may be dissolved in a liquid at the same tension, but the amount of each gas in solution may be very different, depending on the respective solubility of the gases. For example, if 100 cc. of water at 38° C. is exposed to a CO_2 pressure at 40 mm. Hg, it will hold about 3 cc. of carbon dioxide in solution. The same volume of water at the same temperature when exposed to an O_2 pressure at 40 mm. Hg, will hold only about 0.12 cc. of oxygen. The tension of both gases in the solution will, however, be exactly the same.

b. If this water contains some solid substance in solution, it will be able to take up less gas than before the substance was added. The simple solution of gases in blood or blood plasma will be less than in pure water. The presence of proteins or salts in solution depresses the solvent power for gases.

c. Blood may be considered as a fluid tissue, but since it is necessary to deal with tissue properties, it cannot be stated that the gases are held in simple solution as is true of water. However, blood does contain oxygen, carbon dioxide, and nitrogen.

27. Absorption in the lungs.—When gases of the atmospheric air are taken into the lungs and come into contact with the blood by means of the permeable membrane of the alveoli, the physical theory of respiration assumes that the gaseous exchange takes place in accordance with the physical laws of the diffusion of gases; that is, the gas tends to pass through the membrane in both directions to equalize the pressure on both sides. The excess of movement will be from the point of higher pressure to that of lower pressure until equilibrium is established. The combined facors which favor the absorption and

discharge of these gases are properties of the membrane of the alveoli, differences in pressure of the gases, velocity of blood flow through the lungs, and conditions in the blood itself.

28. Alveolar membrane.—The alveolar membrane has three properties which influence gaseous exchange: thickness, permeability, and area. Thickness is less than 1 micron, but there may be familial variations. Permeability is subject to individual variations, depending on cellular arrangement, viscosity, and density. The average constant is 7.6. Area has been estimated to be about 100 square meters. It would require only $\frac{1}{5}$ to $\frac{1}{8}$ of this area to maintain normal respiratory exchange during rest. Schneider states, "The fovea which drives the gases through the alveolar membrane is the difference in the pressures of carbon dioxide and oxygen in the alveolar air of the lungs and the mixed venous blood as it comes to the lungs from the right ventricle of the heart."

29. Alveolar air.—*a.* Individuals live in the atmosphere of alveolar air. This air is made up of supplemental air plus residual air and amounts to about 3,000 cc. However, although about 500 cc. of air is drawn in at an average breath, only about 360 cc. of it reach the alveoli because about 150 cc. are required to fill the dead air space.

b. Alveolar air in resting subjects at a normal atmospheric pressure shows great constancy of composition, although varying somewhat from one individual to another. It is assumed that its composition differs from that of inspired and expired air.

30. Percentage differences.—*a.* Inspired air is made up of oxygen 20.96 volumes percent, nitrogen 79 volumes percent, and carbon dioxide 0.04 volume percent. Expired air contains oxygen 16.4 volumes percent, nitrogen 79.5 volumes percent, and carbon dioxide 4.1 volumes percent. There is no essential difference between the nitrogen contents of inspired and expired air, but the process of respiration has subtracted about 4.5 volumes percent of oxygen from the inspired air and raised the expired content of carbon dioxide to over 4 volumes percent. However, since the expired air is the mixture of alveolar air plus the air from the dead space, it is necessary to discount the air from the dead space in making an experimental analysis of alveolar air.

b. Analysis of alveolar air gives it a composition as follows: oxygen, 13 to 15 percent; nitrogen, 80 percent; carbon dioxide, 4.7 to 6.4 percent; average, 5.6 percent. This air is saturated with water vapor at body temperature.

c. The driving force of these alveolar gases, derived from atmospheric air, depends upon their individual pressures and not primarily upon their percentages. (See par. 31.)

31. Partial pressures.—*a.* At sea level, the barometric pressure of the entire atmosphere is 760 mm. Hg. The partial pressure of each gas constituent of atmospheric air (dry) is the barometric pressure multiplied by the volume percent of the particular constituent. For example, the partial pressure of oxygen at sea level is 760×0.2096 or 159 plus mm. Hg. Nitrogen has a partial pressure of approximately 600. Carbon dioxide exerts practically no pressure at all in perfectly fresh air. One atmosphere of gas pressure means a pressure equivalent to 760 mm. Hg, and in any given mixture, the pressure of any one constituent may be expressed in fractions of an atmosphere or in the equivalent height of a mercury column which it will support.

b. When air reaches the alveoli of the lungs, it has absorbed water vapor. The tension of this aqueous vapor at 37° C., which is approximately body temperature, amounts to 47 mm. Hg. Therefore, to compute the pressure of the air in the depths of the lungs, it is necessary to deduct the pressure of the water vapor as follows: 760 mm. Hg minus 47 mm. Hg equals 713 mm. Hg, or the pressure of air in the alveoli.

c. Calculations derived from this alveolar pressure and the percentage composition of alveolar air show that the partial pressure of each constituent of alveolar air is oxygen, 102; carbon dioxide, 40; and nitrogen, 571 mm. Hg.

d. When the gas tension of the alveolar air on one side of the pulmonary epithelium is compared with that of the blood on the other side, it is found that the pressure differences are such as to enable gaseous interchange to take place by the simple process of diffusion. For example, the oxygen tension in alveolar air is about 102 mm. Hg and in venous blood is about 40 mm. Hg. This makes a pressure difference of at least 60 mm. Hg on the two sides of the membrane to favor the drive of oxygen into the venous blood. Also, the carbon dioxide tension in alveolar air is 40 mm. Hg and in the venous blood is 46 mm. Hg, which makes a small pressure difference of 6 mm. Hg. However, since carbon dioxide passes very readily through the pulmonary epithelium, this small difference in tension is sufficient for its elimination. In fact, a difference of carbon dioxide tension across the lung membrane of 0.12 mm. Hg is sufficient to enable the resting output of carbon dioxide to occur. The tension of nitrogen in venous blood is 570 mm. Hg.

e. Arterial blood has an oxygen tension of 100 mm. Hg, a carbon dioxide tension of 40 mm. Hg, and a nitrogen tension of 570 mm. Hg.

32. The carriage of oxygen.—*a.* After oxygen has reached the blood through the permeable membrane of the alveoli, it is not held there in simple physical solution. This fact is evident because there is such a large quantity present and because the quantity does not vary directly with the pressure in the surrounding medium.

b. It has been proved that by far the largest portion of this oxygen is held in chemical combination with the hemoglobin of the red corpuscles. A much smaller portion, which varies with the pressure, is held in solution in the plasma. Although the latter amount constitutes only about 1 percent of the total oxygen, it is a very important factor because it is in equilibrium with the alveolar air and also determines the quantity of oxygen which shall be held in combination with the hemoglobin.

c. The blood is exposed to the alveolar air over a very extensive surface. The film of blood is one corpuscle in thickness and it circulates through the lungs once a minute during rest and as often as ten times a minute during hard muscular work. These factors favor the transport of oxygen.

d. The volume of the blood bears a definite relationship to surface area and to body weight. To a square meter of body surface the volume is 2,500 to 4,000 cc. and of the plasma 1,400 to 2,500 cc. Roughly estimated, whole blood is about $\frac{1}{11}$ and the plasma $\frac{1}{20}$ of the total body weight. The blood volume of an average sized man of 154 pounds would be about 6,300 cc.

e. The arterial blood contains 14 percent hemoglobin by weight, and each gram of hemoglobin can take up 1.34 cc. of oxygen. Therefore, 100 cc. of arterial blood would have a capacity of 18.8 cc. of oxygen. This concentration is, however, variable in different races of people.

f. Oxygen in combination with hemoglobin forms oxyhemoglobin. This is a definite chemical structure, subject to the laws of mass action and reversible in conformity with the equation Hb plus O_2 equals HbO_2. It is not a stable compound and is subject to ready dissociation when the pressure of oxygen in the surrounding medium falls below that in the hemoglobin. This power makes possible the delivery of oxygen to the tissues.

33. Curve of O_2 dissociation.—The amount of dissociation, or the reduction of oxyhemoglobin to reduced hemoglobin which takes place under different pressures of oxygen in the surrounding medium, and a dissociation curve of hemoglobin, which is of great physiological importance, are given below.

a. Several samples of whole blood are placed each in a separate closed vessel and exposed to known oxygen tensions: 0, 10, 20, 40, and 100 mm. Hg. They are rotated continuously in a water bath at body temperature until equilibrium has been established. The proportion of oxyhemoglobin to reduced hemoglobin is then determined. The results are plotted on a chart with the oxygen tensions along the abscissae and the percentage saturation along the ordinates. The curve so formed will be doubly inflected or S-shaped.

b. From the above it will be seen that at 100 mm. Hg, which is the partial pressure of oxygen in the arterial blood, the hemoglobin is about 95 percent saturated. An increase in oxygen tension beyond 100 mm. Hg would increase the oxygen combining power of hemoglobin but slightly. There occurs relatively little reduction in the percentage saturation of the hemoglobin until the oxygen pressure has fallen to about half its value. At 70 mm. Hg the hemoglobin is still 90 percent saturated. There is a maximum saturation with oxygen so long as the oxygen pressure is above 80 mm. Hg as found in the lungs and a rapid liberation of the gas at the lower oxygen pressures as prevail in the tissues.

c. When the same experiment is carried out with a solution of hemoglobin in distilled water instead of whole blood, the curve of dissociation will form a rectangular hyperbola instead of an S-shape. This means that the hemoglobin as such would show a great avidity for oxygen as it exists in the lungs but would not yield up its oxygen load until the partial pressure in the tissues had fallen to a very low level. Therefore, at the pressures which exist in the tissues the rate of dissociation of oxyhemoglobin would be many times slower than its rate of formation, and hemoglobin alone would be worthless as a carrier of oxygen.

d. The discrepancy between the behavior of a simple hemoglobin solution and whole blood is explained by the fact that the blood contains carbon dioxide, inorganic salts, a high concentration of hemoglobin in the corpuscles, and is at a temperature of 37° C. When these factors are adjusted to simulate body conditions, the solution itself will behave like blood; that is, the curve will take on an S-shape, thus indicating a facilitation in the delivery of oxygen at tensions which exist under tissue conditions.

e. The presence of carbon dioxide produces a change in the reaction of the blood toward the acid side and causes the curve of dissociation to flatten to the right. This means that the affinity of hemoglobin for oxygen is reduced. Lactic acid produces similar results.

Both carbon dioxide and lactic acid are evolved from tissue activity and act to alter the H-ion concentration of the blood.

f. The addition of dissolved inorganic salts in appropriate concentration may make the curve more S-shaped under certain conditions, but it is of less importance than previously supposed.

g. The strength of the hemoglobin solution examined is significant. In weak solution (1:500) the curve is always hyperbolic, even in the presence of salts or under acid, alkaline, or neutral conditions. The addition of salts to a medium strength solution will produce an S-shaped curve. The maximum concentration of hemoglobin (30 gm. Hb to 100 cc. of corpuscles) in the red blood cells is one of the chief factors in producing the S-shaped dissociation curve of the blood.

h. When the temperature of the solution is raised to 37° C., or that of the body, the curve also tends toward an S-shape.

i. All these factors in combination cause the hemoglobin to give up its oxygen more readily at the lower oxygen tensions, but they participate very little in the acquisition of oxygen at the higher tensions.

34. Summary.—*a.* As a summary, the extent of dissociation is dependent upon oxygen tension, CO_2 tension (and H-ion concentration), electrolyte content, temperature, and concentration of hemoglobin. The rate of dissociation will depend upon CO_2 tension, and temperature.

b. Oxygen has been absorbed from the alveolar air by a simple process of diffusion due to differences in tension of the gases as they exist in the media of alveolar air and blood; oxygen is transmitted in solution in the plasma and in chemical combination with the hemoglobin of the red corpuscles; certain conditions must exist in order that the oxygen may be liberated from the blood to supply the tissues of the body.

c. Practically no oxygen is lost from the arterial blood until it reaches the capillaries. It still retains a high pressure head of oxygen in solution. Oxygen tension in resting tissues is estimated at about 35 mm. Hg. Therefore, oxygen can readily pass out of the plasma through the capillary wall and tissue fluid to reach the tissue cells. The oxygen tension in the blood will fall to about 40 mm. Hg, which is the tension of the venous blood. At the same time the oxyhemoglobin in the corpuscles, having been exposed to a tension of 40 mm. Hg in the plasma, will be dissociated and will liberate about 30 percent of its oxygen to the plasma. This amount of gas cannot remain

in solution in the plasma which holds all it can, so it diffuses out into the tissue fluid.

35. Coefficient of O_2 utilization.—*a.* The fraction of the total oxygen content of the blood which is given up to the tissue is called the coefficient of oxygen utilization. For example, the stated arterial blood (hemoglobin) content of oxygen was 18.8 cc., but, since about 30 percent was lost in contact with the tissues, the venous blood would have an oxygen content of 13 plus cc., or a difference of 5.6 cc. percent. The coefficient of utilization would be 0.29, or 29 percent. The coefficient varies considerably for different tissues and according to their degree of activity and rate of blood flow. The tissue takes what oxygen it needs for its activity and leaves the rest.

b. No discussion is given in this manual on the process of oxidation as it takes place in the tissues of the body, and reference should be made to some standard textbook on physiology. In general, the subject entails a study of oxidative and other complicated chemical reactions which are dependent upon the existence of various types of enzyme systems and electrolytic phenomena within the tissues. With present knowledge, no coordinated account is possible.

36. Acidity and alkalinity.—Any account of respiratory control and of carbon dioxide carriage in the blood would be somewhat obscure without prior consideration being given to the regulation of the blood reaction. The comparative constancy of this reaction is evident in health and in many disease conditions, and is dependent on the ratio of carbon dioxide (H_2CO_3) to sodium bicarbonate ($NaHCO_3$). It is this ratio which determines the hydrogen-ion concentration of the blood. In order that the maintenance of the hydrogen-ion concentration be understood, it is necessary to consider the present day conception of acidity and alkalinity.

37. Ionization.—*a.* There are substances, known as electrolytes, whose molecules may be dissociated into constituent ions. An ion is an electrically charged atom or group of atoms, and is referred to respectively as a cation or anion according to the nature of the charge, positive or negative, which it holds.

b. Pure water may be considered such an electrolyte and in ionization it dissociates to give rise to positively charged H (hydrogen) ions and negatively charged OH (hydroxyl) ions, according to the reversible equation H_2O=H plus OH. It is a perfectly neutral solution, and the H and OH ions are equal in number.

c. The amounts of ionic H and ionic OH in pure water have been determined and are expressed in terms of gram equivalents per liter of the solution. There is 1 gram equivalent ionic H in 10 million

liters of water; also the same equivalent ionic OH in the same amount of water. Therefore, in terms of ionization, pure water is a $\frac{1}{10,000,000}$ normal acid and a $\frac{1}{10,000,000}$ normal alkali. Instead of expressing the hydrogen-ion concentration of water as $\frac{1}{10,000,000}N$, the logarithmic notation is used and expressed as 10^{-7} N. To avoid the negative index, the notation 10^{-7} may be replaced by the letter P, which signifies that the negative exponent to the base 10 is employed. In the case of pure water, the value would be pH7, the hydrogen-ion concentration of a neutral solution. Any exponent above 7 indicates an alkaline solution, and an exponent below 7 indicates an acid solution.

d. The acidity of any solution is due to a preponderance of H ions and the alkalinity to a preponderance of OH ions. Strong acids, such as hydrochloric (HCl), and strong bases, such as sodium hydroxide (NaOH), are very completely ionized, while weak acids, such as carbonic (H_2CO_3), and weak bases, such as ammonium hydroxide (NH_4OH), are very slightly ionized. All acids and bases combine with one another in chemically equivalent proportions.

38. Buffer system.—*a.* When an acid or base is added to a buffered solution, there are substances present which maintain the solution at a relatively constant pH. These substances are called buffers and have the power to "soak up" or "tampon" the acid or base; that is, they take up the shock of a strong acid or base, hence the term "buffer."

b. A buffer or a buffer system is made up of two parts: a weak acid and one of the salts of that acid. Examples are carbonic acid and sodium bicarbonate; phosphoric acid and sodium phosphate. The hydrogen-ion concentration of a buffer solution is proportional to the ratio of the concentration of the free acid to the concentration of acid bound with alkali, or—

$$\frac{\text{concentration of free acid}}{\text{concentration of bound acid}}$$

c. Acids are constantly being formed in the body during the process of metabolism. For example, CO_2 results from oxidation of all foodstuffs; H_3PO_4 (phosphoric) and H_2SO_4 (sulphuric) result from the oxidation of the phosphorus and sulphur of ingested protein; HL (lactic) forms during muscular activity and may be excessive in the blood in strenuous exercise. In diseased conditions, beta-oxybutyric and acetoacetic acids may be produced in excessive amounts.

d. Basic radicals, potassium, sodium, calcium, magnesium, are taken in large amounts in the ordinary diet, especially in vegetable food, and must be disposed of to prevent excessive alkalinity of the blood.

39. Reaction of the blood.—*a.* In health, the reaction of the blood remains remarkably constant at about pH 7.4, which is slightly alkaline. Its reaction may, however, range between pH 7.05 (in exercise) on the acid side and pH 7.85 (during deep breathing) on the alkaline side. Even in disease little variation may be shown.

b. The reaction of the blood is protected by three lines of defense: the buffer system of the blood, excretion of carbon dioxide by the lungs, and excretion of fixed acids by the kidneys. The intestinal mucosa also assists to some extent in the removal of acid, especially a part of the phosphoric.

40. Action of buffers.—*a.* The buffer system of the blood exists as primary buffers in the plasma and as secondary buffers in the corpuscles.

(1) In the plasma, the buffers are as follows:

(*a*) Free carbonic acid and acid bound as sodium bicarbonate—

$$\frac{H_2CO_3}{NaHCO_3}$$

ratio 1 to 20.

(*b*) Acid and alkaline phosphates of sodium—

$$\frac{NaH_2PO_4}{Na_2HPO_4} \quad \frac{\text{(acid Na phosphate)}}{\text{(alkaline Na phosphate)}}$$

ratio 1 to 5.

(*c*) Plasma proteins behaving as acids—

$$\frac{\text{H protein (free)}}{\text{Na proteinate (bound)}}$$

(2) In the red corpuscles, the following buffers are present:

(*a*) Oxyhemoglobin and reduced hemoglobin which act as weak acids, while the potassium salt acts as alkali—

$$\frac{HHbO_2\ \text{(H oxyhemoglobinate)}}{KHbO_2\ \text{(K oxyhemoglobinate)}} \text{ and } \frac{HHb\ \text{(H hemoglobinate)}}{KHb\ \text{(K hemoglobinate)}}$$

(*b*) The potassium salts of phosphoric acid—

$$\frac{KH_2PO_4\ \text{(acid potassium phosphate)}}{K_2HPO_4\ \text{(alkaline potassium phosphate)}}$$

b. The reactions by which acids are buffered are as follows:

(1) The fixed acids, lactic, phosphoric, sulphuric, etc., which are formed during the metabolic processes, are buffered by means of the bicarbonate. For example, HL (lactic acid) plus $NaHCO_3$ (sodium

bicarbonate) = NaL (sodium lactate) plus H_2CO_3 (carbonic acid). The comparatively strong fixed acid is thus replaced by a neutral salt. The lactate may be excreted in the urine. Lactic acid may also be removed to a large extent through its conversion to glycogen in the muscles and liver. CO_2 diffuses into the alveolar air.

(2) Some of the fixed acid reacts with the alkaline phosphate to form a salt of the acid and a greater proportion of acid phosphate. For example, HL (lactic acid) plus Na_2HPO_4 (alkaline phosphate) = NaL (sodium lactate) plus NaH_2PO_4 (acid phosphate). The excess acid phosphate is excreted in the urine. The phosphate system is less efficient than the bicarbonate system for the removal of excess acid because excretion from the kidney is relatively slow and base is lost from the body in combination with the acid.

(3) The plasma protein neutralizes fixed acids as follows: HL plus Na protein = NaL plus H protein.

41. Kidneys.—The kidneys have a role in the maintenance of normal acid base balance. They not only respond to the minutest variation in blood reaction by secreting more acid or more alkaline urine but also tend to normalize the proportion of soda, potash, and other crystaloid substances existing in the blood. They eliminate many fixed acids in the form of the salts of these acids, chlorides, phosphates, carbonates, lactates, and sulphates. Ammonia, formed in the kidney from urea, combines with these acid radicals. When there is a tendency to acidemia, the kidneys excrete acid phosphate, thereby rendering the blood more alkaline. When alkalemia impends, the alkaline phosphate and possibly also bicarbonate are excreted to restore the balance. The kidneys constitute an extremely important compensatory mechanism.

42. Gastrointestinal tract.—The role of the gastrointestinal tract is much less important. However, when large quantities of free hydrochloric acid are secreted into the stomach, the urine becomes alkaline in the endeavor to restore normal equilibrium. This is known as the alkaline tide which occurs during the period of active gastric digestion. When free HCl passes into the intestine and is neutralized by the bases, it is reabsorbed into the blood stream, thereby restoring the bicarbonate and chloride concentration to normal levels. The alkali of the urine then disappears and the reaction becomes more acid.

43. Carriage of carbon dioxide.—The lungs and the process of breathing have first rank in the regulation of the blood reaction. The carriage of carbon dioxide by the blood and the intimate rela-

tionship it bears to the buffering reactions of the red corpuscles and plasma are given below.

a. Carbon dioxide is transported by both corpuscles and plasma of the blood. In the arterial blood, the content of carbon dioxide ranges from 50 to 53 volumes percent and in the venous blood from 54 to 60 volumes percent (the number of cc. of CO_2 per 100 cc. of blood). There is a gain of 4 to 11 volumes percent of carbon dioxide as the blood passes from the arterial to the venous side of the circulation.

b. Experiments have shown that blood at 37° C., when exposed to a pressure of 40 mm. CO_2, which is about that of arterial blood, will hold in physical solution only about 2.7 volumes of carbon dioxide per 100 cc. of blood. Therefore, the greater part of it must be held in some kind of chemical combination.

c. The chemically bound carbon dioxide is carried in the blood combined with a base, to form a bicarbonate or carbonate. This bound form may be designated by the symbol $BHCO_3$, while the free form is expressed as H_2CO_3.

d. If all the carbon dioxide were in the free form, the blood would be a thousand times too acid and if it were in the form of carbonates, the blood would be hundreds of times too alkaline, both incompatible with life. The maintenance of the reaction necessary to sustain life demands a constant balance between H_2CO_3 and $BHCO_3$. (See par. 37.)

e. When carbon dioxide enters the blood from the tissues, it combines with water to form H_2CO_3. Practically all of the H_2CO_3 thus formed then combines with a base to form bicarbonate. It finds this base principally in the proteins which are already combined with weaker acids.

44. Hemoglobin.—*a.* Hemoglobin supplies directly and indirectly the greater part of the base used for the following reasons: it comprises about three-fourths of the total protein in the blood; it holds in combination an even greater proportion of the base held by weak acids in the blood, because it has so many weak acid groups in its molecule; it has the power of altering its acid strength with its degree of oxygenation. "It is almost as completely responsible for the transport of carbon dioxide in the blood as it is for the transport of oxygen. Of the alkali furnished to neutralize the carbon dioxide that enters the venous blood, from 80 to 95 percent, sometimes possibly all, comes from the hemoglobin. Of such alkali, the greater part is set free when the relatively strong acid, oxyhemoglobin, is changed by loss of oxygen to a weaker one, reduced hemoglobin,

which is itself an efficient buffer of blood reaction. The relatively slight remainder is furnished by other buffers—phosphates in the cells, proteins in the plasma, and the bicarbonate."

b. That reduced hemoglobin, as its exists in the blood after the extraction of oxygen for tissue metabolism, is more effective than oxyhemoglobin in conveying carbon dioxide can be demonstrated by comparing the CO_2 dissociation curves of reduced and oxygenated blood. The method is similar to that used for the determination of the O_2 dissociation curve, except that the blood is exposed to an appropriate series of CO_2 tension. This experiment demonstrates that at any given CO_2 pressure, reduced blood is able to take up more carbon dioxide than oxygenated blood and gives further evidence that hemoglobin is intimately related to CO_2 carriage. It is obvious that in proportion, as hemoglobin gives up its oxygen for tissue anabolism, it becomes more effective as a carrier of carbon dioxide.

45. Red blood cells.—The red blood corpuscles contain certain weak acids which are hemoglobin and phosphates (KH_2PO_4 and K_2HPO_4). Although these weak acids are combined with base in the corpuscles, they will release their base in the presence of stronger acids. After carbon dioxide has combined with the water of the blood to form carbonic acid, it will act as a stronger acid. When this diffuses into the corpuscles it reacts with the potassium of the hemoglobin as follows: H_2CO_3 plus KHb=$KHCO_3$ plus HHb. Also, it combines with the phosphate in the following way: H_2CO_3 plus K_2HPO_4=$KHCO_3$ plus KH_2PO_4.

46. Plasma.—The plasma of the blood also has an important role in the transport of carbon dioxide. It contains proteins and, like the hemoglobin, these can act as feeble acids and combine with bases which can be removed again by stronger acids. In the presence of carbonic acid the following reaction occurs: Na protein plus H_2CO_3=$NaHCO_3$ plus H protein.

47. Chloride shift.—Plasma contains sodium chloride and the carbonic acid reacts with this to break it down into the Na cation and Cl anion. The hemoglobin of the red cells, by virtue of its K radical, is capable of withdrawing the Cl from the plasma to form KCl, thereby leaving the sodium to form $NaHCO_3$ with the carbonic acid. As the CO_2 tension of the blood increases, the chloride of the plasma decreases, the chloride of the corpuscles and the bicarbonate of the plasma increase. This is known as the chloride shift and is a reversible reaction. The fact that the envelope of the red cells is not permeable to hemoglobin and to cations (K and Na) but is permeable to anions (CO_2 and Cl) makes possible the reactions which occur.

48. Diffusion of CO_2.—Arterial blood reaches the tissues with a carbon dioxide tension of 40 mm. Hg. Since the carbon dioxide tension of resting tissues is probably 46 mm. Hg or more, there will be a diffusion of carbon dioxide into the venous blood until the tension at rest amounts to 46 mm. Hg. During exertion, the local carbon dioxide tension may rise to 60 mm. Hg with a consequent increase in venous carbon dioxide tension, a greater reduction in oxyhemoglobin, a larger amount of base transferred, and a greater increase in bicarbonate formed.

49. Lungs.—*a.* The blood, carrying its load of carbon dioxide, now passes to the lungs. Here it is exposed to an alveolar carbon dioxide tension of 40 mm. Hg. Due to the difference of pressure on the two sides of the membrane, carbon dioxide will diffuse out of the blood into the lungs. This diffusion is very rapid and is abetted by the presence in the red cells of an enzyme, carbonic anhydrase, which accelerates the disintegration of carbonic acid into carbon dioxide and water (reversible). In addition, the rapidity of diffusion may possibly occur because some of the carbon dioxide seems to be carried in direct combination with the hemoglobin, so that it does not initially go through the stage of carbonic acid.

b. The carbon dioxide tension in the aveoli does not rise in spite of the addition of CO^2 because the breathing is regulated at a level which is sufficient to wash out as much CO_2 as is coming from the blood. At the same time, the blood is becoming oxygenated and assuming a greater avidity for base than the reduced hemoglobin. Therefore, the proteins of the blood become dominant and the CO_2, deprived of base, cannot remain in the blood which holds as much CO_2 as it can in solution. It passes out into the lungs in the proportion of about 4 cc. per 100 cc. of blood at rest.

50. Chemical control of breathing.—The nervous control involving the respiratory center, in conjunction with the carotid body, was outlined in section II. Chemical changes which further affect this control, inasmuch as carbon dioxide is so eminently responsible for it, are given below.

a. The fact that variation in the carbon dioxide tension of the alveolar air is associated with such profound changes in respiratory activity led Haldane to the hypothesis that the carbon dioxide tension of the blood is an important factor in the control of respiration. The hydrogen-ion concentration of the blood was considered important by other investigators and the well-known effect of oxygen deficiency in the stimulation of respiration had also to be borne in mind.

b. Best and Taylor state, "There are many points which could not be reconciled with the idea that the hydrogen-ion concentration of the blood is a significant factor. Sodium carbonate and sodium bicarbonate produce quite different effects on respiration. Bicarbonate stimulates respiratory activity while carbonate depresses it when concentration of the salts which produce the same change in hydrogen-ion concentration of the blood are used. Administration of gaseous mixtures with a low oxygen content increases pulmonary ventilation in spite of the fact that a definite increase of the pH of arterial blood is produced. When oxygen is given, the respiration returns to the normal level while there is a decrease in the pH of the arterial blood."

c. The experiments on isolated cells demonstrated that intracellular hydrogen-ion concentration does not vary directly as the hydrogen-ion concentration of the blood under certain conditions.

d. The theory has been postulated that the hydrogen-ion concentration of the respiratory center itself was the governing influence by which the chemical influences could be correlated. An excess of carbon dioxide and fixed acids in the blood (as in strenuous muscular exercise) produces a direct excitation on the center, presumably by raising its H-ion concentration. Severe oxygen lack may excite the center directly, but acts mainly upon the carotid sinus mechanism and ultimately depresses the center. Under physiological conditions, the CO_2 tension in the blood, not the O_2 tension, is the controlling factor. An accumulation of CO_2 would stimulate the center long before the oxygen tension of the blood fell to a level sufficient for stimulation. Severe oxygen lack increases chiefly the rate of respiration, although eventually damage to the center and depression of respiratory activity supervene. Excess of carbon dioxide increases chiefly the depth of breathing and decreases the sensitivity of the Hering-Breuer reflex.

SECTION IV

ANOXIA

51. Definition and types.—"Anoxia" is a term used to describe oxygen lack in the body from any cause. The term "anoxemia," sometimes employed, has the more restricted meaning of oxygen lack in the blood. There are four recognized types of anoxia:

a. Anoxic type.—Where the tension of oxygen in the arterial blood is lower than normal, and as a result, the hemoglobin is not normally saturated with oxygen.

b. Anemic type.—The oxygen tension in the arterial blood is normal, but the quantity of functioning hemoglobin is too small.

c. Stagnant type.—The oxygen tension and oxygen content of the arterial blood are normal, but it is supplied to the tissues in insufficient amounts.

d. Histotoxic type.—The tissue cells are poisoned so that they are unable to make effective use of the oxygen supplied to them.

52. Anoxic type.—*a.* The anoxic type of anoxia is very serious because the tension of oxygen in the blood is too low and the tissues are thereby hampered in several ways; their rate of oxidation is diminished, less oxygen is present in the blood and any activity which demands more oxygen consumption is impossible, and the oxygen present in the blood does not readily dissociate from the hemoglobin, owing to the low carbon dioxide tension.

b. The causes of anoxic anoxia are varied and may be classed under the following headings:

(1) *Low oxygen tension in the inspired air.*—This condition is caused by high altitudes and occurs characteristically in aviators, mountaineers, and in rebreathing tests. It may also be due to the vitiation of atmospheric air by inert gases.

(2) *Alteration of the alveolar epithelium.*—In this condition, the walls of the alveoli are swollen and edematous or are covered by a layer of fibrous exudate, thus prohibiting a ready diffusion of oxygen. Irritant gases, as chlorine, and edema of the lungs in heart failure are potent causes.

(3) *Partially unventilated areas of lung.*—Due to the low oxygen tension in the underventilated alveoli, the blood leaves them undersaturated with oxygen and not enough oxygen is taken up in the remaining alveoli to compensate for this defect. The conditions where this situation is found are in shallow breathing (neurasthenia after gassing or shell shock, surgical shock, influenza, or pneumonia), in emphysema, lobar pneumonia, collapse of the lung, and obstruction of the air passages.

(4) *Abnormalities of heart and blood vessels.*—If the blood is shunted from the right to the left side of the heart, as through a

patent foramen ovale or septum, a portion of the arterial blood has not passed through the lungs at all and anoxia is present.

53. Anemic type.—*a.* The anemic type of anoxia is less serious than the anoxic form because in it the oxygen tension of the blood is normal and the rate of tissue oxidation is maintained. No increase in pulmonary ventilation results, which suggests that breathing does not respond to decrease in the amount of oxygen in the blood providing the oxygen tension is normal. The individual, who suffers from the anemic type, may have very few symptoms while at rest because only 5 cc. of the 19 cc. of oxygen normally contained in arterial blood are used up in the resting condition. However, the capacity for work is cut down proportionately as the oxygen reserves of the body are diminished.

b. The causes of anemic anoxia are:

(1) *Hemorrhage, or anemia from any cause.*—The effects of hemorrhage depend not only on the amount of blood lost but also on the rate at which the loss occurs. A large hemorrhage produces fall of blood pressure from lowered blood volume, a diminished venous return, a lessened output of the heart, subnormal body temperature, and symptoms of oxygen lack as giddiness, faintness, and possibly loss of consciousness. In the severe anemias, such as pernicious anemia and leukemia, the total hemoglobin content is diminished and the venous blood is much reduced. What hemoglobin is present holds its full load of oxygen, but a great fall of oxygen pressure must take place in the capillary blood in order that the tissues shall receive their quota of oxygen and the smaller number of red cells must give up a larger part of their oxygen load than normally. In exercise, the cardiac output must be greatly increased in order to increase the oxygen supply to the tissues.

(2) *Carbon monoxide poisoning.*—Carbon monoxide combines with the hemoglobin of the blood and renders it unfit for oxygen carriage: HbO_2 plus CO=HbCO plus O_2. The affinity of carbon monoxide for hemoglobin is about 300 times that possessed by oxygen. The presence of HbCO alters the dissociation curve of the functioning hemoglobin so that the hemoglobin will only give off oxygen in appreciable amounts when the oxygen tension is very low. It thus prevents adequate amounts of oxygen being delivered to the tissues. Lack of oxygen carriage causes death before tissue respiration can be specifically affected by the carbon monoxide. The symptoms are those of oxygen lack. When over 50 percent of hemoglobin is thrown out of action, the slightest exertion may cause fainting; when the

saturation is over 80 percent, the outcome is fatal, although this may occur with 60 percent saturation. There is no appreciable increase in breathing and no "air hunger," because the oxygen tension in the blood is normal. In the treatment of carbon monoxide poisoning, it is possible to displace the carbon monoxide by oxygen if the oxygen tension is sufficiently high and that of carbon monoxide low. Respiration needs stimulation. High tensions of oxygen and 6 to 7 percent carbon dioxide are used in the treatment. The use of a pressure chamber will increase the oxygen tension beneficially. Although methylene blue has been advocated in the treatment, probably because it is known to accelerate tissue oxidation, it does not relieve the true situation owing to the fact that carbon monoxide poisoning is not lack of oxygen utilization in tissues but lack of sufficient oxygen carriage by the blood.

(3) *Poisoning by nitrites and chlorates.*—Nitrites produce nitric oxide hemoglobin and some methemoglobin; chlorates produce methemoglobin. The individual may be markedly cyanosed due to the presence in the blood of this coffee-colored substance. However, since the arterial oxygen tension is normal, there may be no special complaints. If oxygen is breathed for a sufficiently long period, methemoglobin gradually disappears and recovery occurs, at least in exposed animals. It is theoretically possible that the blood may contain a reducing agent which strives to convert the methemoglobin to reduce hemoglobin. In case death does not occur, there is a partial excretion of methemoglobin, the reducing agent gets the upper hand, and the oxygen-carrying power of the blood is restored.

54. Stagnant type.—The stagnant type of anoxia occurs when the circulation rate of the blood is diminished. In this type, the saturation of the arterial blood, its total oxygen load, and its oxygen tension are all normal. However, a considerable portion of the oxygen supply is delivered under low pressure because each portion of the blood gives up a larger part of its load due to the slower flow of blood and its longer stay in the capillaries. The stagnant type occurs in the following conditions: circulatory failure, obstruction of the venous return from the part, as local anoxia, and surgical shock. Under normal conditions, the application of cold to a part will produce a local stagnant anoxia. While the increased reduction of oxyhemoglobin is taking place, the impaired circulation is also causing an accumulation of carbon dioxide, which in turn facilitates the giving off of oxygen.

55. Histotoxic type.—The histotoxic type of anoxia occurs in poisoning with cyanide and narcotics. Although there is no interference with oxygen carriage by cyanide, it depresses tissue oxidation by paralyzing the respiratory enzymes which are responsible for normal oxidation in the tissues. In the treatment of this condition methylene blue may be used. It is believed that it acts by forming methemoglobin which in turn combines with the cyanide to form cyanmethemoglobin. This latter compound is relatively nontoxic and is broken down slowly. The detoxification of cyanide is probably brought about by conversion to thiocyanate. Other substances, such as amyl nitrite, sodium nitrite, and various sulphur compounds are effective in the treatment of cyanide poisoning by forming methemoglobin which reacts as above. Narcotics also depress tissue oxidation. It is believed that they act on the dehydrogenase systems which normally activate the hydrogen of metabolites (for example, lactic acid) and thus enable them to combine with the oxygen which is bound with a series of pigments called cytochrome. In the presence of narcotics, cytochrome remains oxidized and does not become reduced by other cell constituents, thereby impairing the activity of tissues.

56. Nervous reactions.—*a.* Anoxia in general affects the nervous system according to its degree. The factors which influence this degree are the suddenness of oxygen decrease, extent of oxygen decrease, length of time it is decreased, and physical condition of the individual. When anoxia is very rapid, there may be a loss of consciousness without warning so that the individual drops as though felled by a blow. An example is a miner who breathes methane gas. A more gradual development will produce dulling of the intellect and senses without subjective awareness. Relief of the anoxia will cause great surprise because of the seeming increase of power or visual acuity.

b. Symptoms such as headache, depression, drowsiness, apathy, excitement, and loss of self-control, may be present and resemble those of alcoholism. Shouting, singing, crying, quarrelsomeness, disregard for self-safety, overconfidence in judgment, impairment of memory, and time appreciation may be some of the concomitants. The capacity for self-analysis is lost. Understanding is affected more than sensation so that printed or written words have little meaning. Pain is dulled. Finally, each sense is lost suddenly, hearing being the last to succumb.

c. There may be incoordination of movement, unsteadiness when walking, and eventual collapse due to loss of power in the legs. The muscles are weak, and the individual fatigues easily.

d. Nervous tissue is especially sensitive to the lack of oxygen. Cerebral cells cannot be revived after 8 minutes of complete deprivation; cerebellar cells after 13 minutes; medulla oblongata after 20 to 30 minutes; spinal cord cells after 45 to 60 minutes; the autonomic ganglion cells after 3 to 3½ hours; the myenteric plexus cells after 7 to 8 hours. It is therefore obvious that severe anoxia, such as may occur with carbon monoxide poisoning, may be followed by a serious disturbance in the mental life of the individual.

57. Gastrointestinal symptoms.—The gastrointestinal symptoms are anorexia, nausea, and vomiting. Thirst may also be present.

58. Circulatory reaction.—The circulation shows first an increase in frequency and apparent force of the heartbeat and possibly a small rise in blood pressure. This is caused by a stimulation of vasomotor and cardio-accelerator centers. Later the heart force may subside, although the acceleration may increase. Cyanosis may accompany the condition.

59. Cyanosis index.—*a.* The degree of the cyanosis is a rough index to the degree of the anoxia. The color is due to the large proportion of hemoglobin to oxyhemoglobin. It may result from a local or general slowing of the blood, or from an imperfect oxygenation of the arterial blood. The color varies according to the fulness in the capillaries, blackness indicating full vessels and grayness showing small or contracted vessels in extreme cases. In mild cases, full vessels have a blue appearance and constricted ones a purplish red hue.

b. If the anoxia be due to an alteration of the dissociation curve by a diminution of the carbon dioxide in the blood, it indicates a failure of the blood to dissociate its oxygen to the tissues not in perfect saturation with oxygen. Therefore, the blood will leave the tissues without having given up its proper proportion of oxygen and there will be little or no cyanosis. In these cases, the anoxia will be greater than is suggested by the color. Cyanosis is a useful index, if too much stress is not placed upon it.

60. After effects.—It is evident that the after effects of anoxia will depend in general on the length of exposure. Short exposures, even though producing unconsciousness, are followed by no harmful effects. However, peculiar behavior, such as quarrelsomeness, gig-

gling, etc., may be an aftermath. Longer exposures (45 minutes) will be followed by headache, fatigue, exhaustion, or subnormal temperature. Severe and prolonged exposures produce coma and slow return of consciousness, partial paralysis or muscular convulsions, loss of memory or mania, dilation of the heart with irregular and feeble pulse and possible injury to the respiratory center. Recovery, especially of the nervous tissues, may take months and is usually complete if death does not occur during the first few days.

61. Classes of reactions.—From a physiological standpoint, the reactions to anoxia may be classed as transitory or permanent.

a. The transitory reactions are found in anoxia of a few minutes to several hours duration and for our present consideration are manifested best in aviation and mountain climbing. They may be simulated experimentally in the low pressure chamber, nitrogen breathing, and the Henderson-Pierce rebreather for altitude classification.

b. The permament reactions are demonstrated most effectively during residence at high altitudes.

SECTION V

EFFECTS OF CHANGES IN ALTITUDE

62. Barometric pressure.—*a.* The barometric pressure at sea level is 760 mm. Hg, but as altitude increases, the barometric pressure decreases. With the decrease in barometric pressure, there is a corresponding decrease in the pressure of oxygen, until an altitude is eventually reached where the oxygen pressure is insufficient to sustain life under ordinary conditions.

b. The composition of atmospheric air is given in paragraph 22, and it is stated that the partial pressure of each constituent is the barometric pressure times the volume percent of the particular constituent. In the case of oxygen, with a volume percentage of 20.96 under an atmospheric pressure of 760 mm. Hg, the partial pressure is 159 mm. Hg.

c. The passage of oxygen from the atmospheric air into the living tissues is determined by the pressure of oxygen rather than its percentage. In the following table the barometric pressures, oxygen

pressures, and the oxygen percentage equivalents for these pressures, corresponding to various altitudes, are given:

Height (feet)	Barometric pressure	O_2 pressure	O_2 percent equivalent
0	760	159	20.96
3,281	670	140.4	18.4
6,562	593	124.5	16.4
9,842	524	109.8	14.5
10,300	506	105.9	13.0
13,123	463	97	12.7
16,404	410	85.9	11.3
18,000	380	79.5	10
19,685	357	74.8	9.8
22,966	320	67	8.8
28,000	253	53	6.9
40,000	149	32	4.2
50,000	90	18.8	2.4

d. The actual supply of oxygen as regards quantity is the same at any altitude, but in order that it may be available for the human organism it must be under a pressure great enough to be driven into the blood. For example, at 40,000 feet the oxygen pressure is only 32 mm. Hg and, since the body is accustomed to an oxygen pressure of approximately 159 mm. Hg, there will be an oxygen want at that altitude because the partial pressure of the oxygen is far too low.

e. The alveolar air is our immediate source of oxygen supply. Although the pressure of atmospheric air at sea level is 760 mm. Hg, the pressure in the alveoli is 713 mm. Hg, after deducting 47 mm. Hg for the water vapor pressure. Also the atmospheric air has become diluted by the residual air in the lungs so that oxygen, for example, is reduced from 20.96 volumes percent in atmospheric air to approximately 14.3 volumes percent in the alveoli of the lungs. Here it exists under a partial pressure of about 102 mm. Hg instead of 159 mm. Hg, as it did in atmospheric air. The partial pressure of oxygen in alveolar air is nearly 35 percent less than that of atmospheric air at all altitudes.

f. When the surrounding atmospheric pressure, and consequently the alveolar pressure, is decreased, there will result an anoxic anoxia which becomes increasingly severe as the partial pressure of oxygen is diminished. Finally a height is reached where the pressure under which gases are held in the tissues would become greater than the

surrounding pressure, and the blood instead of taking up oxygen would theoretically give off nitrogen. This process would be akin to caisson disease and dilute the alveolar air still further.

63. Altitude ceiling.—*a.* It has been estimated that the limit or ceiling for man is between 40,000 and 50,000 feet, probably about 43,000 feet. At this latter height, breathing pure oxygen is physiologically comparable to breathing air at 15,000 feet, which is usually regarded as the safe limit of height for flight without oxygen. When 61,000 feet and above is reached and the atmospheric pressure is reduced to 50 mm. Hg or less, which is approximately equal to the normal water vapor pressure in the alveoli, it is obvious that no gas, even though breathed in 100 percent concentration, would be absorbed by the blood.

b. Great altitudes have been reached in open cockpit airplanes and sealed gondolas, and the present trend is the construction of airplanes with sealed cabins in which normal atmospheric conditions may be simulated. With the aid of oxygen, Soucek was able to reach 43,000 feet in an open cockpit airplane; Picard in August 1932 ascended to 53,000 feet in a pneumatically sealed gondola; Settle and Fordney reached a height of 61,236 feet in November 1933; Stevens and Anderson in a specially constructed gondola attained an altitude of 72,395 feet in November 1935; Swain, of the Royal Air Force, wearing a sealed flying suit, ascended to 49,967 feet in September 1936. In each case the maintenance of a sufficient supply of oxygen made the flight possible. Possibly the ideal conditions will be approached by the construction of supercharged, sealed-cabin airplanes in which crew and passengers exist in atmospheric air regulated to normal barometric conditions. At present airplanes of this type have been and are being constructed, and a great amount of experimentation is going on to overcome the many problems contingent upon such an innovation. This is of great importance from both civil and military standpoints in aviation.

64. Physiological reactions to altitude.—The physiological reactions to altitude are reflected upon the human organism in various ways Permanent effects, as found in persons residing at high altitudes, can be studied very readily; transitory effects, as shown by aviators, may be simulated by means of the low-pressure chamber and the Henderson-Pierce rebreather, and thus lend themselves to more controlled observation.

65. Henderson-Pierce rebreather.—The Henderson-Pierce rebreather is an apparatus consisting of a closed 52-liter tank of air to which the subject is connected by two tubes supplied to one mouth-

piece through which he breathes. With nostrils closed off to external air, the subject inhales air from the tank through one tube containing check valves and exhales air through the other tube equipped with check valves. The outflow tube connects with a cartridge of dry sodium hydroxide which absorbs the exhaled carbon dioxide. A spirometer is introduced into the circuit. The amount of air at the beginning of the test is regulated by introducing water into the tank and as the oxygen is absorbed, it is replaced by the addition of water. The subject's physiological reactions are observed in the response of heart rate, blood pressure, and rate and depth of breathing; his psychological reactions are determined by his response to flashing lights, variable ammeter readings, and variable sound motor. Analysis of the air from the tank at the termination of the experiment will give the final percentage of oxygen. The decrease in oxygen percentage is equivalent to a decrease in barometric pressure, because by reducing the oxygen percentage in air, the partial pressure of the gas is also reduced.

a. Rebreather reactions.—Rebreather runs were made on one series consisting of 1,050 cases. This showed two types of reactors; "fainters" and "nonfainters." It was found that 46.7 percent of the aviators were likely to faint under lowered oxygen percentage, while 53.3 percent of the cases did not tend to faint. The fainters as a class are considered unfit for very high flying. A comparison of the two types is given in the following table:

Final oxygen tolerated in percent	Percentage of nonfainting group becoming inefficient	Percentage of fainting group becoming inefficient
11 plus	----------	0.7
10 to 10.9	0.6	.7
9 to 9.9	1.2	13.0
8 to 8.9	13.0	30.9
7 to 7.9	40.1	41.7
Below 7	45.2	13.0

The final oxygen percentage for all cases gave an arithmetical mean of 7.42 plus 0.01 with extremes of 11.1 and 5.2. The mean length of the test was 24.7 minutes, with some as long as 35 minutes.

(1) *Fainting type.*—The fainting type demonstrates the fact that the brain centers. which control heart rate, diameter of blood vessels, and rate and volume of breathing are likely to suffer from

paralysis before the higher or psychic centers are affected. There are three subgroups of this type, dependent upon which brain center is first seriously impaired.

(*a*) A large number show an initial fall of blood pressure, indicating a failure of the vasomotor center. In some, the systolic pressure falls first; in others, the diastolic pressure is first to fall; in the remainder the two pressures fall together. The administration of oxygen will stop the process immediately and ward off the attack of fainting.

(*b*) A second group shows the advent of fainting by a slowing of the pulse rate. This is caused by a stimulation of the cardio-inhibitor center or by a direct effect upon the pacemaking tissue of the heart.

(*c*) The third group of fainters manifests a sudden decrease in the minute volume of breathing, probably due to a paralysis of the respiratory center by a lack of oxygen.

(2) *Nonfainting type.*—(*a*) The nonfainting type demonstrates a paralysis of the psychic centers before the vasomotor, cardiac, and respiratory centers become paralyzed. The majority of these men can be carried into unconsciousness and will sit at least for a few moments, quite erect while the heart rate and respiration continue to increase. As shown by the table, 85 percent of this group tolerate a low oxygen percentage without marked loss of efficiency. Some of this type, however, cannot be trusted to fly at altitudes as high as 15,000 feet because they show mental inefficiency at moderately low (10 percent) oxygen. Their adaptive mechanisms either fail to respond to the stimulus of oxygen lack, or they respond inadequately.

(*b*) The rebreather test has resulted in no injurious after effects. In tests conducted on 7,000 men, where oxygen want was carried to demoralization of voluntary attention and motor coordination or to the point of fainting, there was not an instance of injury to the subject. Frequently there was complaint of frontal headache, but this disappeared spontaneously in a few minutes or was alleviated by a cup of coffee. A careful observer never allows fainting to occur. A few deep breaths of fresh air will check the oncoming syncope.

b. Compensatory factors.—The physiological factors which come into play during simulated altitude ascent and compensate for the decreasing oxygen are given below.

(1) *Respiratory compensation.*—A compensatory factor of the first rank is an increase in breathing and the character of the breathing.

Shallow breathing allows only a comparatively small amount of fresh air to get past the dead space to mingle with the air in the alveoli of the lungs. Therefore, the deeper the breathing the greater will be the amount of fresh air in contact with the blood vessels in the alveoli.

(*a*) As a rule, only the depth of breathing is appreciably increased. The rate usually remains unchanged until 8 or 6 percent of oxygen, when it may increase 2 to 4 breaths per minute. The majority of subjects show an increase in depth between 20 and 128 percent when the oxygen percentage is 8.5 to 6. Each breath ranges between 600 and 1,260 cc., while normally the same subjects show a range from 360 to 630 cc.

(*b*) Due to the fact that the depth of breathing is increased, the minute-volume is usually, but only slightly, increased. The fainting type of case showed an increase of 3.5 liters and the nonfainting type increased 5.1 liters at approximately 7 percent oxygen. The percentage increase was only 38 for the fainters and 55 for the nonfainters.

(*c*) The respiratory compensation and alveolar ventilation may be accomplished in several ways; minute-volume increase may be wholly obtained by more frequent breathing; minute-volume may be decidedly increased by deeper breathing; greater minute-volume may be acquired by a decrease in frequency and an increase in the depth of breathing. It is evident that alveolar ventilation is greatest in the third, less in the second, and least in the first.

(*d*) A good respiratory reaction to the gradual decrease of oxygen will be manifested by a slight increase in the depth of breathing, beginning at 16 to 15 percent and progressively increasing slightly until 12.5 to 9 percent oxygen is reached. There will follow a much more rapid increase in depth to 8.5 and 6 percent and an increase in frequency of 2 to 5 breaths per minute. The more effective alveolar ventilation and consequent rise of alveolar oxygen tension will therefore permit the blood to become better saturated with oxygen and create a lower oxygen endurance.

(2) *Sensitivity of respiratory center.*—The respiratory center is not equally sensitive in all men. Some show an increase in breathing at 18 percent oxygen, or an elevation of 4,000 feet. More than 50 percent have the first respiratory response between 16 and 14 percent oxygen; 25 percent demonstrate it at a lower percentage; a few give no evidence of an increase up to the time of unconsciousness. This response was noted in 5 to 14 minutes in rebreathing tests lasting 27 to 30

minutes. Although the organism makes compensatory efforts to overcome the effects of lowered oxygen, the supply of oxygen in the body is being steadily reduced. During the war it was found that aviators who had gone stale from much flying and stress manifested increased frequency of breathing with shallowing. This suggests fatigue of the respiratory center and increases the degree of anoxia.

(3) *O_2 consumption.*—During the anoxia of rebreathing, the consumption of oxygen, which is the best index of the amount of oxidation occurring in the body, was reduced from 4.5 to 26 percent. At an oxygen percentage corresponding to 20,000 feet, the amount of oxygen taken from the blood by the tissues of the arm showed a reduction of 39 percent. This reduction is, however, only temporary when the individual is held at a certain oxygen level, as in the low-pressure chamber. After a period of reduced rate, the oxidation tends to return to normal or to rise above normal. The rise, indicative of excessive metabolic rate, appears to be associated with such symptoms as mountain sickness and is usually temporary prior to acclimatization. It is evident that as the oxygen content of the blood is reduced, the oxidative processes in the body are reduced correspondingly until the compensatory factors assert themselves.

(4) *Vital capacity.*—The vital capacity of the lungs decreases as atmospheric pressure is diminished. This is probably due to a relaxation and engorgement of the pulmonary vessels and their encroachment upon the air spaces. As acclimatization occurs, vital capacity returns to normal. Inhalation of oxygen will normalize the condition because it restores the capillary tonus. Temporary reduction of the vital capacity seems to be without practical importance.

(5) *Circulatory reactions.*—The circulatory reactions observed in rebreathing experiments would tend to indicate that they are distress signals rather than compensatory factors. In a special group study, which included various circulatory conditions (high and low systolic and diastolic pressures, large and small pulse pressures, rapid and slow pulse rates, etc.) it was found that all responded similarly by an increase in breathing and compensated to equally low percentages of oxygen. At least the circulatory conditions did not handicap the body in its compensatory efforts.

(6) *Heart rate.*—When oxygen is reduced, the heart rate is augmented. In the early stages, the acceleration is slight and gradual. It is in evidence at 18 percent (4,000 feet) in 26 percent of all cases, becomes greater at 15 to 12 percent, and may be profound as the limit of endurance is approached. For nonfainters, the mean increase of

heart rate was 28 beats per minute and for fainters 26 beats at the end of the experiment. The greatest acceleration was 62 beats per minute.

(7) *Arterial pressures.*—The arterial blood pressure undergoes certain changes. Nonfainters show a rise of systolic pressure to the end of the experiment. About 44 percent of all cases maintain the normal arterial systolic pressure, or show a rise, up to the time of unconsciousness; the remaining 56 percent show a terminal drop in pressure. The diastolic pressure in the majority of all cases shows a middle period of increased pressure. This is followed by a gradual, controlled fall when about 15 percent of oxygen is reached. In the case of fainters, a period of slow diastolic fall is suddenly changed to a rapid drop which can be checked by the administration of fresh air or oxygen. When systolic and diastolic arterial pressures drop, it is an indication of syncope. A few cases have a slowing of the pulse as the first indication of oncoming syncope. This is closely followed by a fall in the arterial pressures. It is usual that 10 to 7 percent of oxygen, corresponding to altitudes of 20,000 to 28,000 feet, must be reached before the extreme vascular changes associated with fainting are produced.

(8) *Blood flow.*—Anoxia apparently does not affect capillary pressure, but changes in the flow of blood are observed. The flow is first swift and homogenous, but as the oxygen is reduced, a slight granularity appears in the blood and gradually increases with the reduction of oxygen. This granularity is often followed by a clumping of the red cells, the clumps increasing in size as anoxia progresses. Corpuscle-free cylinders of plasma separate the clumps. The rate of blood flow is frequently retarded; in some instances motion ceases; at other times backward pulsations occur. Although variations in the rate of blood flow and appearance of slight granularity are present under normal conditions, the very slow flow and a lack of motion are observed only toward the end of a rebreathing period. All subjects do not show the anoxia change in the capillary flow. Some maintain a rapid homogenous flow throughout the entire period of rebreathing; some have a slight retardation and moderate degree of granularity; others show the entire series of changes. The flow usually returns to normal quickly when fresh air is given.

(9) *Venous pressure.*—Anoxia causes a fall in venous pressure almost without exception. During rebreathing, the pressure is not affected until the oxygen is reduced below 18 percent. It has been demonstrated that the application of abdominal pressure by means of a tightly laced corset has partially prevented this fall of venous

pressure during rebreathing experiments. This serves to indicate that the venous fall is due to a dilation of the splanchnic blood vessels, thus causing a pooling of blood in these vessels. The determination of splanchnic pooling and consequent peripheral vasoconstriction has been made by measuring hand volume by means of a plethysmograph. The change in this case begins earlier than the fall in venous pressure and progresses as the test reaches 7 percent oxygen. Possibly this accounts for the sensation of cold hands and feet during rebreather runs. Recovery varies from 5 to 15 minutes.

(10) *Summary of circulatory effects.*—(*a*) In a summation of the circulatory effects in extreme anoxia, it is evident that there is some degree of circulatory failure as shown from data on the diastolic arterial pressure, venous pressure, hand volume, and blood flow in the capillaries and the hand. This is not due to a failure of the heart's force but rather to a failure of the venous return to the heart. Frequently, in ordinary experience, a fall in diastolic pressure is associated with decreased peripheral resistance due to dilation of the arterioles. However, in the case of anoxia, it appears that the blood is diverted to some extent from the extremities to the trunk of the body and from the periphery of the trunk to its interior. It is evident that the hand volume decreases as anoxia progresses. The tone of the peripheral vessels is not decreased but rather increased, resulting in a retardation in the rate of blood flow through the capillaries.

(*b*) Associated with peripheral vasoconstriction and diversion of blood to the interior is a fall in venous pressure. That splanchnic pooling occurs seems evident from the fact that abdominal pressure will prevent the fall in venous pressure in large measure. Observations made on diastolic arterial pressure demonstrate that in many cases the relaxation of splanchnic vessels occurs gradually but that in fainting the general relaxation of these vessels comes on suddenly.

(*c*) The same circulatory changes occur to some extent in the nonfainters. This is shown by the fact that in a majority of cases there has been some decrease in hand volume, a reduction of blood flow through the hand, a fall in venous pressure, and a slight, gradual fall of diastolic pressure. The nonfainter, however, possesses a more adequate circulation and consequently can withstand a degree of anoxia which renders the higher brain centers ineffective while the lower nerve centers are maintaining effective reflex muscular control. In the fainting type of reaction the medullary centers are profoundly affected before those of the forebrain.

66. Low-pressure chamber.—In addition to the observations which may be made on the Henderson-Pierce rebreather where the

oxygen percentage is gradually decreased, it is possible by means of a low-pressure chamber to simulate actual barometric pressures and to hold the individual at any desired pressure during the course of the observations. The low-pressure chamber is a large and complicated apparatus in which the subject is placed while the pressures within the chamber are varied according to the experimental work desired. For example, the subject may be held in this chamber at oxygen tensions corresponding to altitudes of from 15,000 to 18,000 feet for periods varying from 30 minutes to 2 hours. The time he is so held is called the holding period or hold. During this period, certain physiological reactions may be observed.

a. Respiratory reactions.—(1) Respiratory reactions show that the minute volume of breathing continues to increase for 10 minutes after the oxygen tension level is reached. Following this, the lung ventilation may remain constant for a variable period, but eventually the ventilation suffers reduction. This decrease in the minute volume of respiration takes place only when the other factors of compensation have had time to come into play. In order that this decrease may be effective, the exposure to constant low oxygen must last from 30 minutes to 2 hours.

(2) The partial return of respiration toward normal is believed to indicate a temporary improvement in condition. However, some individuals at the altitude of 15,000 to 18,000 feet show a steady increase in the per minute volume of breathing at the hold, thus indicating that the mechanism is failing to make good.

b. Circulatory reactions.—Circulatory reactions are demonstrated in the behavior of the pulse, blood pressure, and blood itself.

(1) *Heart rate.*—The frequency of the heartbeat increases as the available oxygen decreases, but the maximum efficiency does not occur simultaneously with the arrival at the desired oxygen level. There is a lag of 5 to 10 minutes or more in the development of the maximum rate. After a period of maintained maximum, the heart rate may slowly retard, returning often to the nearly normal rate, or it may slowly continue to accelerate throughout the entire period of the hold. What will happen depends on the adequacy of the other compensations.

(2) *Arterial pressures.*—The systolic arterial blood pressure during a holding period maintains its normal level in the majority of cases. In about 25 percent of cases there is a slight initial rise and then a gradual fall as the experiment progresses. The diastolic pressure ordinarily falls from 4 to 28 mm. Hg in the earlier part of the maintained period. It may later return to normal in some subjects,

while in others it may fall throughout the experiment. It follows from the changes in systolic and diastolic pressures that there is an increase in pulse pressure during the earlier part of the hold and an increase in pulse pressure when favorable compensatory changes occur.

(3) *Blood reactions.*—The hemoglobin and red blood corpuscles of the blood show definite changes during the holding period in approximately 80 percent of all cases at altitudes corresponding to 15,000 to 20,000 feet. These changes are an erythrocyte increase between 4 and 20 percent; a hemoglobin increase between 3 and 10 percent. Both may be demonstrated in capillary and venous blood. It is necessary, however, that the majority of subjects remain at the hold from 40 to 60 minutes for the increases to begin, although about 13 percent of all cases show an increase within a 25-minute period. When the erythrocytes and hemoglobin increase in the blood, the subject shows an improvement in his general condition. There arises an improvement in circulation and sometimes a quieting of respiration. In certain cyanotic individuals, the blood changes produced improved color and increased vigor. An important gain to the body produced by the increase of erythrocytes and hemoglobin is the ability of a unit volume of blood to carry more oxygen than would have been possible otherwise. The natural deduction to be made from this reaction is that the aviator, whose blood concentrates while he is flying at high altitudes, will tolerate the conditions more comfortably and more efficiently than one who does not react in this manner.

(4) *Summary.*—The interpretation to be placed upon the circulatory changes, as demonstrated in the low-pressure chamber during the holding period, is as follows: In the early part of the hold the anoxia gradually increases the demoralization of the circulatory brain centers, producing a slight tendency to circulatory failure as indicated in the pulse rate and arterial pressure changes. Later, because of other compensatory changes, more favorable conditions obtain in the nervous system and as a result the heart frequency decreases, the arterial pressures return toward normal, and the tendency to failure is improved or overcome. When these favorable conditions do not supervene, the pulse rate increases, the diastolic pressure continues to fall, splanchnic pooling occurs, venous return to the heart fails, and the subject becomes ill or faints.

67. Altitude responses of the aviator.—From the observations in paragraphs 65 and 66 it is obvious that certain physiological changes must accrue to any person ascending to an altitude. What

altitude responses may ordinarily be expected from the aviator whose exposure to anoxia is usually of a temporary and emergency nature are as follows:

a. The conclusion must be reached that adaptive changes will vary with the individual capacity to withstand altitude but that certain general reactions will always remain in force.

b. The average flyer, as we observe him today, does not fly at great altitudes where the extreme reactions to oxygen-want occur. If he is compelled to do so, he is equipped with an oxygen supply and uses it to ward off impending trouble. Army regulations require that oxygen be used at an altitude of 15,000 feet, but in cases of individual need and prolonged missions at lesser altitudes, it is necessary to employ it. At present, as larger airplanes with high ceilings are being constructed, the problem of oxygen supply to pilots and crews is an important one. Engineering and medical science are perfecting methods by which great altitudes may be endured safely and comfortably.

c. In the ordinary course of aviation, however, and in indviduals with average reactions, definite physiological changes are always present. Some aviators show a change in breathing at altitudes of 3,000 or 4,000 feet, but the majority do not react until 8,000 feet is reached. The man who breathes deeply is at a much better advantage than the shallow breather. This augmentation in breathing is not large; in exceptional cases it has been as much as 25 liters. The depth is usually increased but the rate is not. Compensation of this type is good, because it allows more air to get by the dead air space and thereby raises the alveolar oxygen pressure. At heights of 15,000 feet, for example, individual differences in the effectiveness of respiratory compensation have been demonstrated. One aviator may show an alveolar oxygen pressure of 54 mm. while another may have only 43 mm. Hg. The pressure difference of 11 mm. Hg between the two means a much greater advantage in oxygen per minute to the aviator who has the higher alveolar pressure.

d. At high altitudes, there is no increase in carbon dioxide in the body, but because of the increased breathing, an excess of carbon dioxide is blown off from the blood. The result of this is to force the hemoglobin to hold its oxygen more firmly than it does at sea level, and in so doing, to place the tissues at a disadvantage for oxygen. The basic cause of this condition is found in the disturbance of the acid base balance of the blood. However, if the individual had an opportunity to remain at that altitude for a long time, compensation would eventually rectify it.

e. During airplane flights, there is some increase in the number of red corpuscles and the percentage of hemoglobin per unit volume of blood. These factors are subject to great individual variation. The adjustive change is not usually apparent below 14,000 feet and may be found in about 80 percent of all men examined. It is evident that the increase in red corpuscles and hemoglobin means that more oxygen can be carried per unit volume of blood for a given oxygen pressure than would be possible otherwise. Therefore, the blood leaves the tissues less depleted of oxygen; the average oxygen pressure in the tissues is higher; and metabolism is better, due to the increased oxygen facility.

f. Variations are further shown in the response of the heart rate. In a few men, the increase is evident at 4,000 feet; in almost all of them it is observed at an elevation of 9,000 feet. It is considered that a total increase of from 15 to 40 beats constitutes a good response to altitudes of about 25,000 feet. The assumption is that the minute-volume output of the heart is increased. The more rapid flow of blood provides the tissues with more oxygen per minute.

g. As the aviator is undergoing the above adaptive changes in breathing, circulation, and blood, the administration of oxygen will cause these symptoms to revert quickly to their low-altitude condition.

h. Although the physiological effects of oxygen want are basic and primarily important, the psychological reactions which accompany them are also of paramount importance. The two effects are so intimately combined that it is impossible to consider one without the other. It is as necessary to know in what manner the mental and nervous processes are impeded by anoxia as it is to understand how the respiratory and circulatory mechanisms respond to it.

i. The excellent research work on the psychological effects of oxygen deprivation on human behavior by Ross A. McFarland, Ph. D., has added much to our understanding of the entire bodily reactions to anoxia. Working with varying gradations of oxygen deprivation, Dr. McFarland studied simple and sensory motor responses, choice reactions, neuromuscular controls, memory, attention, higher mental processes, personality, and fatigue. The conclusions which he reached are here given in condensed form:

(1) Simple sensory and motor responses are not seriously impaired until the subject approaches collapse from O_2 want, and then the loss appears to be fairly sudden. The average subject's simple reaction time was not affected until the O_2 percentage was lowered to 8.87 percent, or approximately 24,000 feet altitude. In many cases, a short period of stimulation or improvement over the normal was

observed in simple responses above 10.25 percent O_2, approximately 20,000 feet altitude, and frequently below 10.25 percent O_2. In most cases, the improvement did not persist long and was followed by a retardation. When O_2 deprivation is prolonged for more than 1 hour, simple reactions are impaired considerably before approaching collapse, and even above 10.25 percent O_2. These results would imply that O_2 want does not impair simple habitual responses until O_2 deprivation has become severe or has continued for at least 1 hour below 10.25 percent without previous acclimatization. Kinesthesis and vision are apparently the first sense categories to be affected, and audition the last.

(2) The choice reactions appear to be impaired at higher percentages of O_2 than the simple reactions. This impairment begins in the neighborhood of 11.43 percent O_2 and gradually becomes worse with increased deprivation. After at least 1 hour's exposure, the effect is usually accentuated. When much prior practice is given in the choice reaction tests, the effect of O_2 want apparently is not so great. However, even then, the impairment comes on gradually above 10.25 percent O_2 and with marked periodicity toward the end of each experimental hour. These findings differ from the results obtained in aviation studies during the war, due primarily to differences in motivation. Pilots naturally exerted great effort to do well, so impairment was frequently not present until impending collapse. The organism automatically adjusts immediately to many of the effects of O_2 want, but generally the functioning is impaired, as in higher mental responses, before acute O_2 want is present or previous to acclimatization.

(3) Impairment of neuromuscular control is affected before the loss of capacity in more highly organized functions and in proportion to the extent of O_2 deprivation, as well as to the length of the exposure. There are great individual differences and the characteristic improvement is frequent. Under actual O_2 want, loss of motor control is very great accompanied by frequent tremors, muscular twitches, unwitting rhythmical movements, and loss of kinesthetic sensitivity.

(4) Loss of memory occurs when the O_2 percentage is as low as 9.05 percent in the average subject. The awareness of the lapse of time is apparently also lost. Memory is affected later and more suddenly than the loss of capacity in choice reactions and neuromuscular control.

(5) The effect of low O_2 on attention was quite definite. Insofar as it limits or narrows the field of attention to eliminating extraneous

factors, it apparently facilitates, but insofar as it undermines voluntary coordination, control or effect, it handicaps. Considerable application of energy is required to counteract the initial drowsiness and lethargy, and there are frequent "attention peaks" associated with either loss of energy or loss of attentive capacity. These reactions show the close interdependence of the muscular sets and voluntary coordination with attention.

(6) Higher mental processes are impaired with the loss of memory and attention, and yet awareness of what is going on persists until the very end. Irrational or fixed ideas are frequent, and capacity for sane judgment and self-criticism is lost. The subject is frequently unaware of his altered behavior. He accentuates acts in the process of execution and continues them with great persistency, although feebly, until just previous to collapse.

(7) The first effects of slight O_2 deprivation on the feelings or moods are frequently stimulating, but if continued for long or accentuated, sleepiness and lack of volition are present. Lethargy and indifference are sometimes overcome by greatly increased effort. If the deprivation is below 9.05 percent O_2, approximately 24,000 feet, unusual emotional outbursts or removal of inhibitions frequently occur, involving loss of esthetic and moral habits and resembling alcoholism. The subject may become hysterical from laughing or very angry, or if opposed, may give up and apparently go to sleep.

(8) Under severe O_2 want, the basic patterns of personality are affected. Not only are sensory and motor defects brought out, but frequently neurotic and emotional tendencies are unmasked. Each subject shows a fair degree of consistency in behavior; that is, he becomes angry or amused or careless or displays no marked emotion. The behavior under O_2 want in each case correlated highly with behavior under alcohol. The results of anoxia tend to show the importance of basic physiological make-up in the formation of personality, as well as the significant part culture or training play in accentuating or masking the native characteristics.

(9) The close relationship between O_2 supply and loss of muscular control and accentuated fatigue was clearly demonstrated. The results also indicate that mental control and fatigue may be related to the amount of O_2 in the blood stream or to the diffusion of O_2 from the blood to the tissues. Many of the observed reactions were similar to those present under continued emotional and mental strain, or in the syndrome frequently called neurasthenia. It is therefore suggested that O_2 want is a prominent symptom in such conditions.

(10) Because of the fact that many of the abnormal reactions produced in normal subjects resemble outwardly many of those found in psychoneurotics (such as impaired motor performance, indifference and lack of voluntary activity, removal of inhibitions and accentuated emotional outbursts, lack of judgment, and of self-criticism) a possible connection between the two is suggested. Although such syndromes are no doubt due to many causes, from subject to subject and from one syndrome to another, the close relationship which an adequate O_2 supply bears to altered metabolism, glandular conditions, acid-base equilibrium, toxic conditions of the cell, etc., suggests that a more intensive biochemical and psychological analysis of this relationship should be made. The results indicate that personality is, in the final analysis, dependent upon certain physiochemical processes, and that more thorough or profound knowledge concerning human behavior may be obtained by combining psychological and biochemical research.

j. In view of the above findings in the studies by Dr. McFarland, it is obvious that oxygen supply to the aviator must always be adequate in order that the untoward reactions to oxygen want may be warded off or eliminated altogether.

Section VI

PERMANENT REACTIONS TO ALTITUDE AND THE TRANSITION PERIOD

68. General.—The permanent reactions to anoxia may be slow in appearing and developing, but they determine the degree and completeness of acclimatization.

69. Passive ascent.—When altitude is reached passively, as in inactive ascent of a mountain, certain changes are manifested in the respiration and circulation. These changes are presented in the paragraphs below.

70. Respiratory events.—*a.* There is an increased ventilation of the lungs, with a corresponding fall in carbon dioxide pressure and a rise in alveolar oxygen pressure as compensation goes forward. At very high altitudes, the respirations increase at once, thus producing a quick fall of alveolar carbon dioxide pressure; at moderate altitudes, the breathing shows no change at first, but after a few days, it is found that the alveolar carbon dioxide pressure has fallen. The increased depth of breathing reaches a certain point, depending on the altitude, and then ceases. These effects depend primarily upon the diminished oxygen pressure of altitude.

b. When an individual remains at the particular altitude, the alveolar changes are not actually completed for several weeks. The table below serves to illustrate the rate of change.

	Percentage of gases in alveolar air		Partial pressure of gases in alveolar air	
	CO_2	O_2	CO_2	O_2
Sea level	5. 55	14. 08	39. 6	100. 4
Colorado Springs	6. 54	12. 94	37. 3	73. 8
Pike's Peak (14,110 feet, 40 minutes after arrival)	7. 8	--------	32. 2	--------
Second day	7. 52	11. 38	31. 1	47. 1
Fourth day	7. 41	11. 26	30. 7	46. 6
Seventh day	7. 21	11. 98	29. 6	49. 0
Twenty-eighth day	6. 63	13. 08	27. 4	54. 0

c. The partial pressure of carbon dioxide is eventually about one-third less on Pike's Peak than at sea level, and it is evident that the alveolar ventilation during rest for an equal production of carbon dioxide at sea level is about 30 percent greater than on Pike's Peak.

d. The volume of air breathed by an individual on Pike's Peak is 27 percent greater during rest in bed, 31 percent greater during standing rest, 50 percent greater when walking 4½ miles per hour, and 100 percent greater during more severe exertion. When at rest, an increase of 30 to 50 percent in the air breathed is not noticeable subjectively; when engaged in hard work, an increase of 50 percent is very noticeable and panting occurs. The hyperpnoea is probably about three times greater than would be the case with a corresponding amount of exertion at sea level. It is found that this condition persists at 14,000 feet during the entire sojourn, but it becomes lessened after the first day or so.

e. At high altitudes, breathing during inaction is usually modified only in depth. If it is 14 to 18 breaths per minute at sea level, it may continue at the same rate at 14,000 feet. However, the same exertion which caused maximal depth of breathing at sea level can only effect the total ventilation of the lungs at altitude by an increase in the rate of breathing.

f. Newcomers at high altitudes may show periodic breathing. This may occur as groups of three or four breaths, each succeeding breath being deeper and each group followed by a pause. If a pause is not present, the groupings may be from 6 to 10, in which there is a gradual increase to the midpoint and then a gradual recession. This phenomenon is probably due to oxygen want, because it can be abolished by the administration of oxygen. It disappears in the majority of cases when acclimatization occurs.

g. Breath holding is decreased at high altitudes. At first this ability may not be impeded, but, day by day, voluntary holding will become harder and the periods of holding shorter. No doubt this is due to a decrease in the alkali of the blood.

71. Blood reactions.—*a.* When the blood is studied at high altitudes, it is found that it takes approximately 24 hours before changes in the number of red cells and the hemoglobin percentage can be detected.

b. A rapid increase in the number of red corpuscles and percentage of hemoglobin occurs during the first 2 or 3 days of residence. This is followed by a more gradual increase extending over 3 to 5 days, or more. For example, one subject at Colorado Springs (6,000 feet) showed a hemoglobin percentage of 109 and a red corpuscle count of 5,992,000; at Pike's Peak (14,000 feet) the hemoglobin was 116, the red cells 6,472,000. In 48 hours, the hemoglobin had risen to 122 and the red cells to 6,800,000. From this point the increase in both was gradual, until in 9 days the hemoglobin percentage was 129 and the red cell count 6,960,000.

c. There are several theories regarding the means by which changes in hemoglobin and red cells are brought about. They may be placed in the following main classes:

(1) Theories which state that the increase is real and not relative, for which there are two explanations; that the increase is due to an increased activity of the blood forming organs, or that the increase is due to a lengthened life of the corpuscles.

(2) Concentration theories which credit the increase per unit volume of blood to an increased concentration of the blood. There is

then an apparent but no real increase in the total number of red cells and amount of hemoglobin.

(3) Unequal distribution of the red cells so that they are more numerous in the blood of the capillaries and smaller vessels and less numerous in the large vessels. This view has not been supported experimentally and seems untenable.

(4) Reserve or dormant supplies of red cells which are drawn upon at high altitudes. Here it is assumed that the initial rapid increase is brought about in part by the outpouring of a large number of red blood corpuscles which previously have remained sidetracked, and in part by a concentration resulting from a loss of fluid from the blood. The later, more gradual increase results from an increased activity of the blood-forming centers. There follows from these activities an actual increase in the total number of corpuscles and amount of hemoglobin.

d. It has been demonstrated that abdominal massage and physical exertion at low altitudes cause an increase in the number of red corpuscles and amount of hemoglobin in the peripheral capillaries; but the same procedures carried out on persons acclimatized to high altitudes fail to change, or actually lower, the number of red cells and hemoglobin percentage. The failure to obtain the increase at high altitudes may be assumed to result from the fact that need for oxygen has already called into the circulation the reserve supply that is present at low altitudes.

e. That an actual concentration of the blood occurs during the first few days was shown by researches made at Pike's Peak. For example, one subject had approximately a 15 percent increase in hemoglobin and a total blood volume 10.8 less at Pike's Peak than were present at Colorado Springs.

f. That there is also an active new formation of hemoglobin and red corpuscles is further indicated. Experiments have demonstrated that stained sections of bone marrow taken from dogs, one group of which had been kept at sea level and the other group at high altitude, showed a decrease in fat cells and an increase in blood elements for the latter group. Furthermore, dogs deprived of the hemoglobin of half their blood supply showed regeneration in about 16 days at high altitudes, while at low altitudes this restoration required 27 days.

g. Physical fitness accelerates the increase in hemoglobin and corpuscles at high altitudes. A sedentary, unfit individual undergoes slow changes and moderate or slight increase. A physically fit person shows a decided rise in the first 24 hours. However, fatigue

delays any increase in hemoglobin and red corpuscles. Physical fitness qualifies the subject to react quickly when under the influence of low oxygen at high altitudes.

72. Heart rate.—*a.* When an individual ascends passively to 14,000 feet, for example, the rate of the heart does not increase immediately. What occurs after the ascent will depend on his physical condition. If he has ascended beyond his own critical altitude line, he is likely to suffer an attack of mountain sickness. If he has not passed that line, his pulse will beat at its accustomed tempo for several hours and if he remains quiet, the pulse will probably not be accelerated until the next morning. Should an attack of mountain sickness be imminent, the pulse rate may reach its maximum by the first morning and decelerate as the attack wears off.

b. In individuals who undergo the physical exertion of mountain climbing, the increase in pulse rate may range from 30 to 74 percent. Inherent physical fitness will determine this increase to some extent, there being a greater augmentation in sedentary and unfit individuals. So far as bodily postures are concerned, the heart is not necessarily more irritable to changes in comparative postures at high altitudes than at low ones.

c. When a sojourn is made at higher altitudes, the pulse rate may show a gradual daily acceleration over a period of 1 or 2 weeks, usually the former. Longer residence establishes a tendency to a return toward the low altitude rate. It appears that the slowing of the heart takes place as other adaptive changes reach their maximum efficiency. There is rarely a complete return to the former rate.

73. Arterial blood pressures.—The value of blood pressure findings at high altitudes has undoubtedly been overestimated. Systolic and diastolic pressures in the majority of young men, observed for a long time at 6,000 feet altitude, correspond to those recorded at sea level in the same age group. Likewise at an altitude of 14,000 feet, arterial pressures show no special change. In an undetermined percentage there will be a fall, while in others who do not react well to altitude, a rise will supervene. In cases of mountain sickness, a definite rise of arterial pressures manifests a disturbance of circulation. The emotional disturbances produced by high altitudes may result in overemphasis on the circulatory conditions observed before the organism has accommodated itself to the new environmental conditions.

74. Capillary pressures.—Capillary pressures were slightly lower at 14,000 feet than at 6,000 feet in some cases, but in many

there was no change. The claim that bleeding from nose, gums, lungs, and stomach commonly occurs at high altitudes is erroneous. There are only a few cases of hemorrhage in many thousands of altitude ascents.

75. Venous pressures.—Venous pressures show no demonstrable differences between sea level and a 6,000-foot altitude, but at 14,000 feet a marked fall was found in young men. These changes occurred slowly, and the venous supply of blood and venous pressures always remained sufficient at the altitude to give a maximum efficiency of heartbeat.

76. Altitude (mountain) sickness.—Since mankind varies greatly in the power of adjustment to changes of environment, it is assumed that mountain sickness befalls some individuals at a lower, others at a higher altitude. But it is certain that no one proceeds beyond a certain elevation, a critical line, unless he experiences the malady. The symptoms of mountain sickness depend not only on the nature of the individual and his physical condition, but especially on the amount of physical exertion made in ascending. The symptoms of mountain sickness persist for 1, 2, and 3 days, and then gradually disappear as the adaptive reactions to high altitude occur. There are two forms of mountain sickness; acute and slow.

a. The acute form is due to going too far beyond the individual critical line. It is characterized by a rapid pulse, nausea, vomiting, physical prostration which may even incapacitate one for movement, livid color of the skin, buzzing in the ears, dimmed sight, and fainting spells.

b. The slow form, manifesting itself later, is due to other debilitating causes besides the barometric depression. It is the more normal type and may produce no symptoms at first. There may be a sense of dizziness on stooping over and raising up. There may be blueness of the lips, edges of the eyelids, gums, and finger tips. Some hours later, the subject becomes disinclined for exertion, rather weak and exhausted. He is restless at night and wakes up with a severe frontal headache. Following this there may be vomiting and a sense of depression in the chest. Exertion may increase the headache. The eyes appear dull and heavy; the tongue is furred; pulse nearly always high (about 100 or over); temperature normal or under; there is anorexia; some have diarrhea and abdominal pain. A tendency to periodic breathing is observed, and physical exertion is accompanied by difficult breathing, especially during physical exertion.

77. Summary.—*a.* In summary, the normal circulatory conditions for the majority of men at high altitudes are an increased heart rate, an unchanged or slightly lowered arterial pressure, and a lowered venous pressure. All investigators have found that altitude produces a marked acceleration of heart rate for the same amount of work done at sea level, although inhabitants at 6,000 feet show no noticeable exercise altitude effect. When the heart rate is accelerated from such exertion, the time of the return to normal after work has ceased is greatly extended.

b. Altitude reactions are most noticeable during the first days and lessen with acclimatization. Arterial pressures are higher after a given rate of walking at high altitudes than after the same rate at sea level. Also, the greater the exertion, the more profound the influence of lowered barometric pressure.

c. Physically fit men react more efficiently to the effects of altitude. Their circulatory mechanisms can withstand the ordinary and extraordinary demands of altitude without the more pronounced acceleration of heart rate and increased blood pressures induced in those less physically capable.

78. Residence at high altitudes.—The physiological adaptations to residence at high altitudes after acclimatization has occurred are as follows:

a. Respiratory reactions.—(1) The mountain dweller has a greater pulmonary ventilation than the dweller at low altitudes. This is accomplished by means of an increased depth of breathing during inaction and a markedly increased rate and depth during exertion. By comparison, the number of breaths per minute at rest are practically the same at sea level and on Pike's Peak, but while walking at the rate of 4 miles per hour on Pike's Peak the breathing accelerates about 16 breaths per minute over the sea level rate.

(2) It is a popular belief that high altitudes increase the size of the chest and vital capacity. Most observers agree, however, that the low atmospheric pressure alone does not increase it. If the chest should actually be found enlarged among mountain dwellers, it may be explained by the increased demand made upon the breathing during muscular effort. A comparison of athletes residing at sea level and high altitude would show similar vital capacities and chest measurements. However, during the period of growth the size of the chest will depend upon the demands made upon it by physical exertion.

b. Circulatory changes.—At altitudes of 6,000 to 8,000 feet there is no augmentation of the heart rate over sea level rate, but at alti-

tudes over 10,000 feet the pulse rate is slightly higher in the mountaineer. Variations in pulse rate are found in different healthy individuals at sea level, and the same limits are applicable to men acclimated to moderate altitudes. Otherwise, except for individual variations, there is no essential difference. The average arterial pressures are not changed in the majority of mountaineers, but there is a slight fall in average venous pressures. After exertion, however, the arterial pressures will be higher than after the same amount of work done at lower altitudes. The greater the exertion the more pronounced will be the influence of lowered barometric pressures.

(1) *Blood changes.*—The blood changes show the hemoglobin content, red cell count, specific gravity, and lymphocytic index to be increased. There is no increase in the leucocytes.

(*a*) The red corpuscles vary, for example, as follows: at sea level, 4.5 to 5.4 millions per cubic mm.; at 6,000 feet, 5.5 to 6.3 millions per cubic mm.; and at 14,000 feet, 6 to 8.2 millions per cubic mm.

(*b*) The percentage of hemoglobin shows the following changes: at sea level, 94 to 106, average 100; at 6,000 feet, 105 to 118, average 110; at 14,000 feet, 120 to 154, average 144.

(*c*) Oxygen capacity of the blood at sea level varies between 17 and 18 cc.; at 6,000 feet between 20 and 21.7 cc.; at 14,000 feet approximately 27.4 cc.

(*d*) The blood of people living at high altitudes fails to show an increase in leucocytes, but it does show an increase in the lymphocytic index. Thus at sea level, this index averages 37; at 6,000 feet, 42.5; at 14,000 feet 50.

(*e*) An increase in the number of blood platelets as well as in the specific gravity of the blood has been observed. The specific gravity, which normally varies between 1.057 and 1.066 in men at sea level, averages 1.067 at 6,000 feet and 1.073 at 14,000 feet altitude.

(2) *Hurtado's observations.*—The work done by Hurtado on the blood characteristics of the Indian natives of the Peruvian Andes, who live at an altitude of 14,890 feet, led him to the following conclusions:

(*a*) There was an average increase of about 1 million red cells per cubic mm. above normal sea level value, but a considerable number had no increase. This indicated that an increased red cell count, although common, was not necessary for life at high altitudes.

(*b*) The average number of grams of hemoglobin per cubic cm. of blood was about the same as the sea level normals. However, 50 percent showed an increase. Each cell contained less hemoglobin than at sea level, and it varied inversely with the number of cells;

that is, the greater the number of cells, the less hemoglobin in each cell and vice versa. The red cell comes to the tissues with a lower oxygen content than at sea level.

(*c*) A marked increase in the size of the red cells was found. This varied inversely with the red cell count. The cell volume was also larger than the sea level normal.

(*d*) The diminished amount of hemoglobin in the larger cell gave a lower value for its concentration, there being only about one-fourth of the cell saturated with hemoglobin.

(*e*) The above findings suggest that the larger surface area in a given volume of blood and in the individual erythrocyte, for the hemoglobin and oxygen content, are the primary factors which favor the supply of oxygen to the tissues. This is the fundamental problem of adaptation to high altitudes.

c. Size of heart.—It is to be expected that living at a high altitude, especially when much physical work is done, will increase the weight of the heart. All muscular exertion tends to increase the weight of the heart and the result of the work at high altitudes would accentuate the tendency. The heart of an Alpine snowbird living at altitudes ranging from 6,700 to 10,000 feet has been compared with the Moor snowbird which is not found above 2,000 feet, and it was found that the average weight of the heart of the Alpine snowbird was about 46 percent heavier than that of the Moor bird. The hypertrophy of the right ventricle was greater than that of the left. One observation of considerable interest was made in which it was found that the heart of a young Alpine snowbird, 1½ months old, had the same proportions in weight as that of the Moor snowbird. This suggested that the differences ordinarily observed at the two altitudes are due to the greater circulatory reactions called forth during muscular work at the high altitude.

79. Summary of hemato-respiratory changes to altitude.—*a.* The whole problem of respiration in anoxia is very closely linked with the control of the chemical reaction of the blood, and, therefore, with the explanation of acidosis. Interest centers about the balance of acids and alkalies because the absorption and unloading of oxygen by the blood is altered by variations in them. Carbon dioxide, by virtue of its acidic character, affects not only the respiratory center but also the dissociation of oxyhemoglobin; an increase in the partial pressure of carbon dioxide augments the dissociation, while a decrease causes the hemoglobin to hold more tightly to its oxygen.

b. It has been shown that in each type of anoxia there occurs an increase in the minute-volume of breathing, and that the increased

ventilation of the lungs lowers the alveolar carbon dioxide pressure. Continued excessive breathing invariably reduces the carbon dioxide content of the blood and changes the acid-base balance of the blood.

c. It has been known for some time that while breathing is increased at high altitudes, the alveolar carbon dioxide pressure is lower than at sea level. To account for this increase in breathing in the absence of an increase in alveolar carbon dioxide, it was assumed that a deficiency of oxygen produces acids that take the place of carbon dioxide in exciting the respiratory center. However, researches have shown that lactic acid, which would naturally be expected, does not accumulate in the blood during residence at a high altitude. Several researches have shown that in the acclimated individual the affinity of the hemoglobin for oxygen is the same as at sea level, if the blood is exposed to a carbon dioxide pressure equal to that of the alveolar air of the altitude. This seems to indicate that the carbon dioxide has been displaced by something which produces an equal effect on the affinity of the blood for oxygen. If the blood of an altitude acclimated person be exposed to 40 mm. of carbon dioxide, the average alveolar carbon dioxide at sea level, the dissociation curve is displaced downward, or to the right, thus proving there has been an increase in acid radicals or a decrease in the bases of the blood.

d. More recently the hemato-respiratory events in anoxia have been following in detail and found to occur in the following order:

(1) The tension of oxygen is decreased in the inspired air.

(2) The deficiency of oxygen that results in the arterial blood because of (1) above causes a stimulation of the respiratory center.

(3) The breathing becomes excessive and carbon dioxide is blown off thereby.

(4) This changes the ratio of H_2CO_3: $NaHCO_3$ in the blood, which means a lowering of the hydrogen ions, an alkalosis of the blood instead of the acidosis of the earlier theory. During this condition, the blood would hold its oxygen more firmly than ordinarily.

(5) Then follows a compensatory disappearance of alkali from the blood. This reestablishes the normal ratio of H_2CO_3: $NaHCO_3$.

e. Haldane gives the following explanation of the hemato-respiratory changes that eventually lead to some degree of acclimatization to high altitudes and the chronic anoxias:

(1) The hydrogen-ion concentration of the blood is regulated with great delicacy by the respiration on the one hand and the kidneys and liver on the other, the respiration doing the rough and immediate work by increasing or decreasing the elimination of carbon dioxide, and the kidneys the finer and slower work by adjusting fixed

alkalies and acids. In anoxia, oxygen want serves as an additional stimulus to the respiratory center, causing an increased amount of carbon dioxide to be washed out of the arterial blood. If anoxia continues, the disturbed acid-base equilibrium must then be redressed and it can only be done by the slow means of regulating. Hence the kidneys and liver slowly redress the balance, the kidneys by excreting the excess of alkali and the liver by suppressing the accumulation of free ammonia. The redressing may require days, or even a week or more, for completion. It is that, however, which gives permanence to the respiratory adaptation of high altitudes. The redressing reduces the total content of blood alkali, but after acclimatization the hydrogen ions are again probably nearly the same as they were at sea level. It is evident that as a result of the redressing process, the total alkalinity of the blood, the alkaline reserve, is reduced in acclimated inhabitants of high altitudes. In airplane flights, the hemato-respiratory changes pass through the first four stages given in *d* above. As a result, the aviator develops an alkalosis but does not remain at high altitudes long enough for the removal of alkali from the blood.

(2) There are certain after effects which follow exposures to oxygen want. They differ somewhat in the aviator and the mountaineer on their descent to low altitudes.

(3) When the aviator develops an alkalosis of the blood during an altitude flight, he will show subnormal breathing for a time after his descent. It will remain subnormal until he has accumulated a sufficient amount of carbon dioxide to reestablish the normal H_2CO_3: $NaHCO_3$ ratio. The time required is from a few minutes to an hour, depending on the degree of alkalosis created by the flight.

(4) The mountaineer, who has already fully compensated, will continue to breathe almost as large a volume of air after his descent as he did at the high altitude. Gradually, in the course of several weeks, his minute volume of breathing decreases to the normal value for the lower altitude. The slow change is due to the fact that his blood alkali has been reduced by acclimatization and it takes time to restore the normal alkaline reserve. The kidneys and liver, which are responsible for restoration, react rather slowly. As long as the alkaline reserve is below normal, the breathing remains excessive for the low altitude.

f. It is evident that mankind must differ greatly in his sensitiveness and power of adjustment to the changes in altitude. His degree of disturbance and his compensatory adjustments will depend upon the rate at which the oxygen is decreased (speed of ascent), the degree

to which it is reduced (height attained), the length of time it is reduced, and to some extent, the physical condition of the individual. The reaction of the aviator is different from that produced by rapid experimental means (nitrogen breathing), or the slowly developed anoxia of the mountaineer. Although an individual's reactions to one of these forms of anoxia may be known, it is not safe to predict how he will react in another. It is possible in the laboratory to learn how he may respond to the conditions of an altitude flight when he is subjected to an anoxia comparable to flight conditions. This is accomplished reasonably well by means of the altitude classification rebreathing tests.

SECTION VII

FATIGUE

80. Definition.—*a.* Everyone knows the meaning of fatigue, because they have experienced it to a greater or lesser degree at some time or other. They recognize the fact that they are not as efficient as usual and are disinclined to continue what they are doing or perhaps to begin something new. Above everything they desire an opportunity to lay aside the affair which instigated their unpleasant state and to find an acceptable form of relief or relaxation.

b. Fatigue has been defined in similar ways by various authors. It has been stated that a person is fatigued when he is capable of less general activity than would be expected from his general mental and physical equipment, and when this diminution in activity is accompanied by a sensation of fatigue or exhaustion or weakness. Another definition refers to fatigue as the sum of the results of activity which show themselves in a diminished capacity for doing work. It has also been interpreted as a progressive flagging of efficiency, together with a subjective sensation of loss of command of the muscles.

c. Knowledge of fatigue has not been definitely coordinated up to this time. Its complex manifestations have been approached from

various angles by the physiologist, psychologist, and clinician, and the consideration of fatigue as an entity is therefore difficult.

81. Types.—*a.* It seems impossible to separate fatigue into explicit types. To state that one type is muscular and another type is nervous is to confuse the issue, because these two mechanisms are intertwined in the production of the symptom complex. If the designation "neuromuscular fatigue" is used, it has more exactness and indicates a respective share by muscular and nervous elements.

b. Excessive muscular work may produce weariness of mind, but the fact that great mental effort may cause muscular weariness is not often brought to the attention. That this condition does arise has been demonstrated, using an ergograph for the purpose. By the use of an electric current, involuntary contractions of the flexor muscles of the middle finger were effected and a certain weight was lifted 53 times before the muscles became exhausted. A severe oral examination was undergone for 3½ hours and it was found that the same stimulation caused only 12 contractions with the same amount of load.

c. "Industrial fatigue" infers a type of fatigue from physical causes. However, it contains additional factors of mental concentration and emotional stress combined with its physical phases. In industry, there is increasingly less simple muscular fatigue as the machines of industry become more intricate and automatic. Especially is this true where danger is involved or where unremitting attentiveness is demanded. The physical work which requires great mental effort and alertness induces fatigue much sooner than does that of a simpler kind. Also, althletic activity of today cannot be characterized as strictly muscular exertion, inasmuch as it too brings into being many mental and emotional elements.

d. Initiative fatigue is a psychological concept which does not seem amenable to any degree of measurement. It is closely allied to so-called industrial fatigue and is theoretically the direct pathway by which environment and the states of mind influence the work output.

e. Other efforts have been made to type fatigue. For example, the following etiologic classification has been given: constitutional; that due to organic disease; neurasthenic types. This classification restricts the general view of the syndrome. Therefore no attempt will be made to adhere to an arbitrary specification of types.

82. Causes.—*a.* In a general sense, physical and mental fatigue result from any activity which involves the expenditure of energy in the body. Schneider ascribes a chemical character to fatigue and says, "It may be the result of a depletion or nonavailability of stores

of energy in the body, or it may be due to the accumulation of end products of metabolism which becomes a hindrance to vital exchanges of the body." He upholds his contention that the reduction in the store of energy-producing substances is a causative agent by citing the fact that the administration of sugar to men doing hard physical labor delays the onset of fatigue. Furthermore, he supports the depletion theory by stating that exhausted runners were found to have a very low content of sugar in the blood.

b. Schneider refers to the importance of oxygen supply in relationship to fatigue. "There is no simpler way of hastening fatigue than to subject the individual to a diminishing oxygen supply." Experimentally, an excised working muscle, which is artificially supplied with oxygen, wards off fatigue and increases its working power.

c. There are certain theories of fatigue which would ascribe it to the formation of waste products in the body during muscle contraction. These products, among which are lactic acid, carbon dioxide, and acid phosphates, apparently depress or inhibit the power of muscles to contract. However, the extent to which some of these substances occur depends in part on the abundance of the oxygen supply to the muscles during their activity.

d. Investigators who experimented with frogs found that when Ringer's solution was first passed through the blood vessels of a working muscle and then through the vessels of a resting muscle, the irritability of the resting muscle was decreased. The latter demanded a stronger stimilus to arouse it, showed a lowered contraction height with a given strength of stimulus, a lessened stimulus frequency for producing tetanus, and decreased work ability and capacity.

e. Theoretically, waste products which may arise from muscular activity, digestive disturbances, or even poor ventilation, affect the glands of the body by suppressing their secretory activity. When formed in large amounts, they permit the passage of albumin from the kidney and accelerate the heart beat by shortening the length of diastole.

f. The injection of adrenalin in dogs that were exhausted on a treadmill caused them to run again. These dogs had not stopped due to the failure of sugar supply nor to a high concentration of lactic acid in the blood. The experimenters supplied a preliminary injection of adrenalin and occasional injections thereafter, but found that these did not increase the dog's capacity for running. Adrenalin was helpful only to the fatigued animal. It is supposed that it acts to restore in part the weakened synthetic capacity of muscles.

g. Schneider says, "Fatigue reminds us of some chemical reactions which are interfered with by the accumulation of the end products. Thus when water reacts with ethyl acetate to form ethyl alcohol and acetic acid, the reaction presently slows and then apparently stops completely before all the ethyl acetate has been converted into its end products. It has been well said that fatigue is not merely the running down of the machine, as in the case of a car lacking gasoline; but rather it is the interference with the mechanism due to accumulation of the products of katabolism, somewhat as the products of combustion by fouling the spark plugs may slow down or stop a motor."

h. When healthy individuals are subjected to exhausting physical exercise, laboratory analysis reveals certain interesting physiological phenomena. The following apparent fatigue changes were found to be present: hemolysis of red blood cells; increased resistance of red blood cells to laking with hypotonic salt solution; increased saturation of hemoglobin by oxygen; migration of chlorides from blood cells to blood plasma; changes in the sulphurs and phenols of the urine; increased systolic, decreased diastolic, and increased pulse pressure; and increased lactic acid production. From these findings, the investigators drew conclusions as follows: fatigue is a phenomenon of changed physiochemical relationship; blood pressure tends to fall into definite fatigue curves; measurement of decreased CO_2 combining power of blood with an increase in CO_2 in the tissues and measurements of metabolism offer reliable quantitative measures of fatigue; muscular fatigue is accompanied by increased white cell count.

i. Although many such physiological researches have been made, one outstanding authority, Mueller says, "No end of physiologic studies have been made on the causes of fatigue. But the question is still open. Body fatigue, i. e., that of the muscles, is attributed to accumulation of fatigue substances and their effect upon the brain. Fatigue poisons, so-called kenotoxins, have been assumed but could never be demonstrated. Lactic acid accumulation in the blood has been found in association with muscle fatigue, and physiologists attribute fatigue to this. It has been demonstrated that during muscle contraction, the blood may contain as much as 100 miligrams percent lactic acid, but here this acid is buffered by the alkali reserve and most of it is eventually resynthesized to glycogen, while the rest is burned to CO_2 and water. Between the nitrogen and phosphorous containing metabolites of muscle and nerve cells and fatigue, no association could be demonstrated."

83. Sensation and feeling.—*a.* Mueller declares that a sharp distinction must be made between the sensation and feeling of fatigue. He says that the sensation is a strictly localizable symptom, while the feeling is part of the general body sensorium. Both of them are subjective phenomena and are demonstrable objectively by a manifest lack of efficiency.

b. The sensation of fatigue, he states, is perhaps associated with circulatory phenomena in the muscles involved, is strictly peripheral and due to changes in the periphery which are transmitted to the center by the nervous pathways issuing from the part where the sensation is felt. He presumes that the peripheral sensation, which is associated with activity of the muscles and nerves of that area, involves the circulation of chemical substances in the blood stream and nervous centers. Also, ionic changes take place in the active nerve and muscle substances as well as in the blood plasma in association with these fatigue phenomena. It has been assumed that the acid reaction associated with contraction of the muscle fibrils transforms insoluble alkaline salts, such as phosphates, into soluble forms, and leads to electrolytic splitting chiefly of the potassium salts. Observations indicate that strong muscle contraction leads to a shift in the calcium and potassium ions from the muscles and nerves into the blood plasma. It has been found also that marked calcium loss in the nervous system leads to marked phenomena of fatigue. Mueller sums up this discussion by saying, "These are some of the known data as regards the physiochemical processes involved in muscle and nerve fatigue. On the whole, this question is still in a state of evolution."

c. Mueller states that the feeling of fatigue is not due to stimulation of the nervous pathways. A feeling is a condition outside of the neurological field, belonging rather to the field of psychology. Fatigue can be "felt" only if we are conscious of the fact that our attention and our power of concentration are decreased and that our capacity for mental effort, memory, and power of expression is giving way; in fact, our reaction time is becoming prolonged. When fatigue reaches a point where our mental perception can no longer grasp the meaning of spoken words or associate them in our memory, it is obvious that the activity of the brain cortex is involved and eventually lost so that sleep ensues.

d. It is considered that the purely vegetative processes, such as digestion, urine formation and excretion, cardiac activity, and breathing are not associated with fatigue. Also, the nervous regulation of intestine and bladder musculature is not subject to it. Vasomotor and respiratory centers, groups of ganglia which regulate body tempera-

ture, and sugar and water content of the blood are apparently unaffected by fatigue processes.

84. Disease; asthenia; emotion.—*a.* Physiological fatigue may arise in any healthy individual in the course of a day's work, but when an individual is ill, it comes on quite independently of physical and mental activity. There is no infectious disease which does not lead to fatigue. It is fatigue which makes the patient aware of his condition and sends him to bed. The reason for the fatigue has not been determined, but it may be the toxic effect on the neuromuscular system, or the excess consumption of energy induced by fever, or the increased calcium content of the blood associated with the illness.

b. Some individuals who are asthenic in body build or psychasthenics, show an increased constitutional predisposition to fatigue. In these neurasthenics, it is a question whether their conditions are actually associated with physiochemica changes or these changes are induced more rapidly and earlier than in the normal individual. Nevertheless, they need more sleep and are capable of less physical exertion.

c. Many observers believe that there is a close relationship between emotion and fatigue. There seems to be no doubt that fatigue is felt when the psyche is profoundly stimulated, especially when the individual is of a sensitive nature and the emotion is fearful and depressing. Crile stated that "Emotion causes a more rapid exhaustion than is caused by exertion or by trauma except extensive mangling of tissue, or by any toxic stimulus, excepting the perforation of viscera." Psychological theory ascribes muscular elements to every emotion, and although outward manifestations may be suppressed by the individual the affective components are always present in increased intensity.

85. Subjective and objective reactions.—*a.* An arbitrary division between muscular fatigue and mental or nerve tissue fatigue cannot be made with any exactness. The same subjective symptoms of irritability, restlessness, inattentiveness, lack of interest, slight headache, and general tiredness may be experienced after a day's work of either physical or mental effort. In fact, it is possible to feel fatigued and tired by night, even though idle all day.

b. It appears that actions and reactions toward the fatigue of strenuous physical exercise differ from those induced by strenuous mental activity, although the feeling is the same subjectively from both causes. Following strenuous physical exertion, complete bodily rest is usually desired, while after mental tiredness some form of physical activity may afford relaxation.

c. Everyone is familiar with the effect of rhythmic, martial music on the reactions of fatigued troops. Their vigor and spirits seem

to return and they go forward with renewed zest. Prior to the sound of the music, it is probable that every muscular contraction was being brought about by voluntary effort; that the actual willing, derived from the higher nerve centers, was the exciting cause of the muscular contractions. With the advent of the sound, however, the act of willing was subordinated and an artificial stimulus (sound) was substituted to create a rhythmic muscular response which required little or no volition and hence served to diminish fatigue.

86. Excessive nerve energy hypothesis.—*a.* Excessive muscular exertion produces definite physiochemical changes in the fluids and tissues of the body and these changes are more marked as the physical exertion is prolonged to the point of exhaustion. The nervous tissues of the body participate to a huge extent in the expression of fatigue. It has been stated, "When we speak of exhaustion in man we mean exhaustion of his brain. This is the central fact." Also, "only cells have the power of transforming energy; the cell being the unit of work, the cell equally is the unit of exhaustion, and the brain cell is the most readily exhausted."

b. In his discussion of fatigue, Grow believes that the physiochemical changes, the "byproducts of excessive physical exertion," are not the true causes of the fatigue syndrome. "It is but natural that this form of energy should produce actual waste products with rather definite chemical findings." He formulates the hypothesis that fatigue is due to the excessive generation of nerve impulses and originates in the nervous tissues of the body. His contention is that the bombardment of our nervous systems with the stimuli which surround our waking selves is sufficient to produce fatigue. Among these stimuli he mentions noise, any vocations containing elements of actual or potential danger, vibration, instinctive fear in the survival of life, real or imaginary worries derived from fear, emotional conflicts, and other besetting stimuli produced by our environment. Grow says, "And so we go about our business of living, unconscious of the wear and tear upon our organism due to the countless assaults of seemingly irrelevant and inconsequential things upon an atavistic part of us that we believe, in our witless self-complacency, we have left behind us eons ago * * *." His conclusions are that in fatigue certain changes probably occur in nervous tissue, but that they have not yet been demonstrated; that the symptom complex of fatigue is due principally to the excessive production of nerve impulses and that so-called muscular fatigue is an adjunct resulting from excessive stimulation, either controlled or uncontrolled; that countless stimuli, acting through the senses, or the direct result of cerebration, induce the

production of nerve energy, that this energy is as real and indestructible as any other form of energy, and that the excessive production of this energy due to excessive stimulation is the primary cause of fatigue; that instinctive and premature fear and the desire of preservation beyond the control of individual experience and conditioning is the basic primary factor activating otherwise harmless stimuli into exhausting nerve-muscle responses.

87. Seats of fatigue.—*a.* The seat of fatigue may be located anywhere from the muscle itself to the cortical centers. Although the whole chain may participate, there is always a weaker link.

b. Schneider lists six probable seats of fatigue; the muscle fiber, motor nerve end plate in the muscle fiber, motor nerve fiber, synapses within the nerve ganglia and the central nervous system, nerve cell body, end organs of sense in the muscle and elsewhere in the body. The statement of Herrick regarding the problem of seats of fatigue is, "The synapses and the motor end plates are probably especially susceptible to fatigue of depression by toxic substances, and the muscle fibers and nerve cell bodies to fatigue of excitation by consumption of their material."

c. From whatever seat fatigue may arise, the stimuli so engendered are admitted to consciousness in a gradually increasing surge until they become interpreted as a feeling of fatigue. The threshold of cerebration allows these afferent stimuli to pass until they become greater than the efferent stimuli which initiated them or until the will-to-do has succumbed to the sensation and feeling of fatigue. Yet will power is able to drive to action long after there is a normal desire to cease. This is due to the conscious or unconscious reinforcement of the efferent central stimuli to counteract the inhibiting afferent stimuli, and is considered the probable basis of all prodigies of action under stress of the emotions. If there is an intimate interrelationship between the sensorium and the muscle, it seems correct to assume that all sensory receptors, interrelated as they are, also have the power of inhibiting the will-to-do and decreasing the amount of expendable nerve force available for the particular act under consideration. The mind must be credited with both reinforcing and inhibiting action. Each sensation induced by the stimuli constantly impinging upon our senses of hearing, sight, smell, taste, touch, and the kinesthetic demands something in return which, by just that much, exhausts the available store of nervous energy. Finally, release is obtained by sleep, thus eliminating the reception of these bombarding stimuli and replenishing the store of energy. Insofar as fatigue is concerned, it is probably quite true as Mueller remarks: "Fatigue can be overcome and

physical as well as mental refreshment can be achieved only by sleep; physical and mental rest cannot accomplish it."

88. Staleness.—*a. Nature.*—Fatigue is regarded as healthy when it is abolished by a night's sleep. When, however, it fails to disappear after a reasonable amount of sleep and persists day after day, it becomes accumulative and is designated as staleness.

Schneider says, "Staleness may result from doing so much in 1 day that it takes several days for recovery. Ordinarily, staleness is not brought on by a single bout of work, although this did sometimes occur during the World War. Staleness is usually the result of doing each day a little more than can be recovered from at night. The only antidote to fatigue is rest; so unless there is sufficient rest, recuperation will not be complete. This means that the daily expenditures of the body are exceeding the income. If this condition continues over a considerable period of time, bankruptcy is inevitable.

There is good reason to believe that the fatigue which leads to staleness has its origin within the central nervous system and that, as a rule, staleness is a neural limitation founded on chemical changes within the body."

b. Symptoms.—As in ordinary fatigue, staleness has both subjective and objective symptoms.

(1) The subjective symptoms are individual factors, varying with the experience of the persons affected. In a general way, there are expressions of tiredness, loss of keenness, lack of refreshing sleep, anorexia, indigestion, constipation, pavor nocturnus, restlessness, irritability, dyspnoea on exertion, heart palpitation, shakiness, and exhaustion.

(2) The objective symptoms are those manifested by the lowering of the capacity for individual performance in the amount of work accomplished. They may be readily observed by the use of performance tests which, by centering attention on automatic physiologic responses to physical work, give us some idea as to the amount of damage that has resulted to the body from the exhaustive effects of accumulated fatigue.

c. Types.—(1) The English Medical Corps during the World War recognized three types of staleness which they named according to the organ systems most seriously affected. Although these types are subject to the same criticism of indefiniteness and overlapping as those of fatigue itself, they are designated as follows:

(*a*) Cardiorespiratory type, in which the pulse rate is increased, is poor in volume and low in tension. Slight exertion causes distress, rapid rise in pulse frequency, and slow return to preexercise rate. The

breathing is rapid and shallow; the extremities of the body are cold and poor in color.

(*b*) Nervous type, which shows poor muscle balance; fine tremors of hands, eyelids, and tongue; greatly increased reflexes; and apprehension.

(*c*) Muscular type, where there is tenderness of muscles, poor muscle tone, with flabbiness and loss of power ranging from slight to marked degree.

(2) It is impossible to draw a clear-cut distinction between so-called industrial fatigue, neurasthenia ("irritable weakness"), and the staleness of the worker. The differences seem to be only those of degree. Furthermore, mental strain over a long period of time, especially when the physical well-being is neglected, may create mental and physical conditions similar to those of staleness. When a man suffers from staleness from whatever cause, he reveals in his automatic responses to physical exertion that the coordinating mechanism of his body is disturbed.

d. Factors producing staleness.—There are many factors which are operative in the production of staleness. It may result from overwork, too little physical exercise, dissipation, excessive emotional experiences, and from repeated loss of sleep. Some of the factors have been scheduled that may operate in industry to predispose the human organism to accumulative fatigue. These may be generally applicable and are condensed as follows:

(1) Length and intensity of activity.
(2) Factory conditions; hygiene and employment management.
(*a*) Physical; time and place of work.
1. Air.—Temperature and humidity; ventilation and room space; dust and fumes; exhaust systems; smell.
2. Light.—Volume; concentration; glare.
3. Noise.—Volume; irregularity; vibration.
4. Accident hazards.—Safety devices; first aid.
5. Feeding.—Sale of food; equipment; service.
6. Sanitation.—Drinking water; rest rooms; baths.
(*b*) Social and economic.
1. Flow of work; depressions and rush orders; routing.
2. Creation of staff; appointment and dismissal; permanency; unemployment; instruction and supervision.
3. Maintenance of production; incentives; discipline.
(3) Nature of the work.
(4) Type of workers.
(*a*) Sex, age, race.

(*b*) Experience.
(*c*) Habits and home conditions.
1. Earnings; thrift.
Food; diet and time of meals.
Stimulants; alcohol and tobacco.
Sleep and recreation; house accommodations and hygiene.
Support of dependents.
2. Method and length of transit from home to work.
3. Duties outside factory.
4. Sexual and family relations.
(*d*) Point of view; trade unionism, patriotism, economic self-interest, herd instinct, etc., general intelligence.

89. Fatigue in aviation.—In military aviation, no great expenditure of muscular energy is entailed, such as that demanded by heavy muscular work. If the fatigue experienced by aviators were typed, it would be somewhat akin to industrial fatigue. That is, although it involves a certain amount of muscular expenditure, it partakes mostly of mental concentration and emotional stress. It is doubtful that the average present day aviator, flying under working conditions as they now exist, becomes so unduly fatigued that he grows stale. That condition might occur under the stress of war or pressing duty, especially in those with defective neuromuscular equipment, but ordinarily his fatigue is of a normal kind, recovered from after the necessary amount of rest. There are reasons why aviation fatigue should be minimized under the present set-up. Some of these are more comfortable and safer ships, with easier maneuverability; better landing facilities; better control of weather flying; greater elimination of noise and vibrations; improved protective devices; shorter and more regular flying hours; presence of copilots; maintenance of better health conditions; more frequent checks on pilots, ships, and equipment to reduce hazard. The amount of stress and strain experienced by one pilot may affect him unduly, while another pilot may not become fatigued under the same conditions. Providing each of them enjoys a normal state of health, the inherent nervous mechanism of one may be inferior to that of the other so that he may react more adversely than the other to the stimuli of his occupation and environment. For that reason it seems necessary to know the man himself, his nervous and physical background, and his capacity to withstand stress and strain before the fatigue problem, if it does arise, can be handled intelligently. In considering the incidence, causes, and prevention of fatigue among flying personnel, there are a number of factors in the

physical, mental, and occupational spheres which are of prime importance. They are as follows:

a. Age.—The younger man in good health and vigor withstands the inroads of fatigue better than the older man. He is not as susceptible to low temperatures, has more endurance, and recuperates more quickly than the man in or beyond the third decade of life.

b. Physical conditioning.—The proper attainment of good physical condition by correct and sufficient exercise is of prime importance. It is reasonable that the pilot in poor physical condition from lack of exercise will suffer more fatigue from the same amount and type of flying than the man who is hard and in good physical trim. When the average pilot started flying training, he exercised and worked actively until he became physically fit, otherwise he would not have survived the ordeal of the training period. After graduation, it is just as incumbent upon him to maintain that state of physical fitness. An actively exercised organism is a source of strength; a neglected and disused one a source of weakness. The pilot should take systematic, well-directed exercise, and his adherence to such a schedule will become evident during the various physical examinations. One of the most important structures on a flying field, from the standpoint of health and morale, is a gymnasium, adequately equipped for handball, squash, volley ball, basketball, and perhaps bowling. Baseball and soccer should be scheduled in season. The flight surgeon should see that these sports are not indulged in to the point of exhaustion, as that would defeat the object of the exercise, that is, the development of a strong, vigorous body, with respiratory, circulatory, and excretory systems trained for the rapid supply of energy-producing materials for complete metabolism, and for effective removal of the waste products of cell activity.

c. Mode of life, work, and recreation.—The pilot's mode of life outside of working hours has a direct bearing on the incidence of fatigue. Besides compulsory athletics, the amount of other relaxation and recreation that he obtains is important. Men who engage in golf, baseball, hunting, fishing, etc., are in better physical condition and better able to withstand fatigue than the men who constantly seek recreation over the poker or bridge table. The pilot who, after flying hours, indulges in some form of dissipation, rapidly uses up his reserves, and lays himself open to the inroads of flying fatigue. The ideal condition is that work, exercise, recreation (relaxation), and rest be properly balanced.

d. Rest.—Recovery from the effects of effort of any type demands rest. Rest is necessary for the restoration of energy-producing mate-

rials in the active tissues and for the elimination of products of metabolism. The type of rest obtained is important and is influenced by the degree or length of time of relaxation. The hours of sleep, correct room ventilation, type of beds used, comfort of the chairs, all enter into the problem of its proper attainment.

e. Diet and elimination.—Diet and elimination are important factors in fatigue. A careful consideration of the physiology of nutrition is essential in order to be sure the individual is consuming sufficient foodstuffs, balanced in proper proportion, to restore the energy-producing material used up in work and to repair tissue breakdown. Here enters the question of underweight and overweight, its relation to physical fitness, and all it implies. Proper elimination of body toxins is very important in delaying the onset of fatigue. Constipation is frequently encountered among pilots due to prolonged physical inactivity and mealtime irregularity accompanying extended tactical or navigational flights. It is essential that the pilot be warned against constipation and advised of the importance of establishing regular daily habits.

f. Ocular fatigue.—This is an important subject and is fully considered in TM 8–300. The following items are listed here for consideration: errors of refraction and muscle imbalance, type of goggles (ventilation and fitting), poor lighting, excessive light, etc. Ocular fatigue encountered in tactical flying and on long flights under conditions of excessive glare (as over water or snow), or under conditions of deficient illumination (as in night flying), tends to increase any refractive error or muscle imbalance, especially if improper goggles are worn. The proper correction or treatment of any ocular abnormality is essential in the prevention of excessive ocular fatigue and its cumulative effects.

g. Mental reactions.—These will be determined by the temperamental type of the individual and must be evaluated from the standpoint of age, home environment, habits, attitude toward flying, etc. Different personalities react variously to the experiences and exigencies of military flying, and for that reason, their individual variations should be known in considering their state of fatigue. This subject is fully treated in TM 8–320.

h. Flying status.—This is a most important item from the standpoint of actual fatigue incidence. It involves such considerations as the number of hours flown daily; regularity of flights; the type of flying (instructional, routine, tactical, navigational, artillery liaison, experimental, test, photographic, etc.); comfort of the airplane in seating arrangement; length of rudder-bar reach; position of instru-

ments; correctness of rigging; ease of control; open, hooded, or cabin cockpits; length of flights between landings; proper preparation for flights or missions; and other related features which may enter into the degree of fatigue induced. It is also very important that the oxygen supply be adequate, especially as is required by regulations, at 15,000 feet altitude or above. It has been found that when oxygen is not used when indicated, excessive fatigue with prolonged after effects results.

After flying over new country, for example, for 8 hours, pilots report that they feel much less fatigued than after doing the same amount of flying over an old, well-known course. Here the elements of interest and nervous activity enter, as also does the question of sense of fatigue. They feel more fatigued after the relaxation and comparative somnolence of a boring flight than after one full of new interest. This sense of fatigue is fallacious insofar as its amount is concerned. Their capacity for work is probably more reduced after the flight over new country than one over well-known routes.

SECTION VIII

EFFECTS OF MUSCULAR EXERCISE

90. Necessity for muscular exercise.—*a.* Exercise is an absolute necessity to promote bodily well-being. This assertion is based on the fact that an organ which is not used eventually atrophies and does not perform its proper function. It is only the demands made upon an organ that cause its development, and after reaching that development, its level cannot be maintained without proper use.

b. General exercise builds up health and vigor. If it is performed sensibly according to the needs of the organism, it increases alertness, cheerfulness, high morale, elastic step, healthy complexion, and capacity for arduous mental and physical work. Lack of necessary physical training produces irritability, morbidness, petty ailments, low morale, easy mental and physical fatigability, and complaints of constipation, headache, nervousness, and insomnia.

c. There is a physiologic need of a primitive kind of exercise which cannot safely be eliminated by civilization. In the early days of

civilization, man was compelled to utilize his muscular equipment extensively to combat his environment. In this modern day, his neural mechanism is in greater demand. The modern man must therefore frequently initiate his muscular activity in order to compensate for its ordinary lack in the business of living. Specialization in industry, city and community life, present day transportation, the telephone, and modern inventions have detracted from the amount of muscular effort necessary to approach the problems of life. In fact, it is most important that systematic muscular exercise be afforded to balance the drains made upon the neural mechanism.

d. Man actually possesses a much larger proportion of physical factors than he needs for a sedentary existence. His muscle is in excess of his ordinary requirements; his lung surface and heart tissue are greater than his comparatively easy life demands. If he fails to call into play this extra tissue, it tends to atrophy and become a source of weakness to him. Since large portions of the central nervous system have been set aside for the control of muscular activity, it, too, must be put to proper and greater use by directed exercise.

91. Aims of exercise.—The aims of exercise are to remedy pathological conditions, to influence growing conditions and aid in the development of structure, and to maintain somatic vigor and produce resistance to fatigue, disease, etc.

a. For the maintenance of somatic vigor, the amount of exercise taken need not be great. It should, however, be sufficient to produce general effects and to place real demands on the respiratory, circulatory, and heart regulatory mechanisms. It should promote metabolism.

b. Five groups of muscles induce the general effects of exercise. These are the flexors and extensors of the thighs, the abdominal and back muscles, and the shoulder muscles. The general effect is not well obtained if one group alone is favored.

c. The changes which take place in the body from well-controlled exercises are quite striking. It has been demonstarted that in exercised animals, the weight of the heart, kidneys, and liver had an average excess of about 20 percent, while the spleen showed a similar amount of deficiency. The brain weight was increased about 4 percent, while no change was observed in the spinal cord. The ovaries gave an excess of 34 percent and the testes 12 percent. The ductless glands such as the pituitary and the suprarenals responded by changes according to sex. The bones showed increased density and changes in the cancellous plates so that their lines of stress may be tolerated more effectively. Exercise tends to thicken and toughen the

sarcolemma of the muscle fibre and to increase the amount of connective tissue within the muscle. The muscle increases in size, although there is reason to believe that the number of fibers within it do not increase.

d. The gain in muscle power is out of all proportion to the gain in size. It is evident that training improves the quality of the muscle contraction. This improvement in quality may be associated with an actual change by which fuel is made more available and stored in greater amounts, and oxygen is more abundant due to a better circulation of the blood. Furthermore, the glycogen content of worked muscles is more abundant, the quantity of nonnitrogenous substance is regularly augmented, and the content of hemoglobin increases.

e. It has been suggested that the facility of transmission of the nerve impulse across the motor end plate in the muscle fiber is one of the gains of training. If such a condition obtains and the idle muscle fibers are developed by training, it is apparent that it becomes easier to use the muscle in its entirety.

f. A trained, exercised muscle learns the best combinations for use. Superfluous contractions are eliminated and precision and endurance are increased thereby. It is not sufficient simply to build big muscles, for although the size appears extraordinary, they may not be improved necessarily in quality nor skill which comes only from the establishment of good coordination.

92. The internal environment.—*a.* If graded exercise is taken day after day, the amount of work may be increased gradually until that which was exhausting can be comfortably carried. Schneider says "The muscular capacity of a man is measured by the extent to which he can call upon his body for increased effort. Work is comfortably accomplished only provided the performer can maintain an approximate equilibrium between the oxygen required by his muscles and that which he absorbs. The largest load of work for which the balance between demand for and intake of oxygen is maintained is the so-called crest-load. The size of the crest-load is increased by training."

b. It has been observed that the quantity of oxygen absorbed by a subject as a result of training was not changed for moderate loads of work, but with a load of 6,000 foot-pounds, it rose from an early training average of 1,760 cc. to 1,950 cc. in the late part of the training period; and, with a load of 7,000 foot-pounds, it rose from 1,880 in the early training to 2,150 cc. in the late training period. The conclusion was that "the improvement in ability to supply oxy-

gen is what should be expected where overloads become normal loads, if it be admitted that breathing and circulation of the blood are improved by training."

c. The body is therefore able to increase its margin of response, and this may be measured by the increase in capacity for muscular work and the increase in respiratory exchange. Muscular training not only increases the margin of response, but also the ease with which work is performed. Ease of performance is brought about by a greater economy in the expenditure of energy, since the body as a whole becomes more efficient in a mechanical sense.

d. In the early part of a training period, more muscles are utilized than is necessary and larger amounts of carbon dioxide are discharged. It has been determined that for a given amount of work the amount of carbon dioxide eliminated is greater if the subject has received no previous training.

e. The usage of oxygen between trained and untrained men has been compared. Both were tested by lifting a load of 20 kilograms. The duration of the working period which brought on complete fatigue averaged 25 minutes with the trained men and only 6.4 minutes with the untrained men. The oxygen required for the trained men averaged 2,010 cc. per minute and for the untrained 2,314 cc. per minute. Where work continued to complete fatigue, the oxygen debt in the trained group was 9.9 percent and in the untrained 37.8 percent of the oxygen requirement. The men without training spent 23 percent more energy in the initial work, which occupied 3 minutes and 20 seconds, and 54 percent more in work up to complete fatigue.

f. Improvement in efficiency is expressed by the decline in total metabolism and is probably due to an increase in skill and in the mechanical effectiveness of the muscle itself. Skill varies widely with individuals as does also the amount of oxygen required. Investigations on runners of different experience have shown that the least skillful subject uses one-half more fuel than the most skillful. The athletes demonstrate a smaller consumption of oxygen and a higher net efficiency than the nonathletes.

g. Failure to meet the oxygen demand during a period of physical exertion is reflected in the accumulation of lactic acid in the blood. Accompanying this, there is a diminution of blood bicarbonate and a fall in the hydrogen-ion content. Exhaustion may be the final outcome of these changes. In comparisons between athletes and nonathletes, it has been shown that the trained man is able to reconvert the lactic acid that forms in his muscle to glycogen as rapidly as it is formed even during severe exertion; while with the untrained man,

lactic acid escaped from the muscles into the blood during comparatively mild exertion. The changes in the lactic acid and in the bicarbonate content of the blood are approximately reciprocal.

h. By comparing the hydrogen-ion content of the blood of the trained with that of the untrained man, it has been found in a specific example that the athlete had a decrease of only 0.02 from the normal after a load of work requiring 2,000 cc. of oxygen per minute, while the nonathlete showed a decrease of 0.15 from the normal after the same load. The greater shift in the hydrogen-ion content of the blood in the nonathlete was in harmony with the changes in the lactic acid and bicarbonate.

i. When the untrained individual cannot supply an adequate amount of oxygen to the muscles, it results in a considerable discharge of lactic acid into the blood stream. Here it becomes neutralized by the sodium of the sodium bicarbonate, and in serving as a buffer, the bicarbonate is destroyed. This obviously upsets the alkaline reserve, because the presence of bicarbonate is necessary to maintain it. When this reserve becomes decreased, the power of performance is limited. Physical training actually increases the alkaline reserve. However, it has been found that if this training exceeds the physiologic limit, there is an increased hydrogen-ion concentration of the urine. This does not appear in the trained athlete, and he may secrete a more alkaline urine after intense muscular exercise.

j. In the words of Schneider "It is evident that one important feature in the superiority of the athlete lies in his ability to maintain the internal environment of his body nearly constant, even during very severe exertion. This we have found he manages to do by supplying a more adequate amount of oxygen to his muscles and by maintaining a larger alkaline reserve than does the nonathlete."

k. Although not all aspire to be athletes, the nearer their training and bodily efficiency are approached, the better will internal environment be administered.

93. Respiratory changes.—There are certain well-defined changes in the respiratory mechanism and its functioning brought about by physical training.

a. The expansion of the chest is increased, the rate of breathing is slowed, and the depth of breathing is augmented. Training renders the entire lung volume readily accessible, so that the blood may be exposed to oxygen over as much as 100 square meters of surface.

b. The inefficient individual has very little movement of the diaphragm and breathes with increased respiratory frequency. The athlete possesses deep diaphragmatic breathing and a slow breath-

ing frequency. Lung capacity cannot always be judged by external measurements since they take no account of the diaphragm.

c. Youth is the opportune time for chest development, because exercise results in enlargement of the chest during growth and influences the size thereafter.

d. Muscular exercise causes the trained man to breathe less air and absorb a greater amount of oxygen from it. The reduction in volume is very gradual, but it was first observed during the second week of training and reached its maximum reduction in about 7 weeks. The analysis of exhaled air showed also that the trained man absorbed a greater amount of oxygen, meaning that the breathing became more economical over a period of training.

e. According to Schneider, the percentage of carbon dioxide in the expired air is roughly 6 for the trained man as against 4 for the untrained man. This indicates that the trained man ventilates his lungs both during rest and in exercise more economically than the untrained. The advantage in this in exertion is that the athlete has an increased utilization of oxygen and an increased production of carbon dioxide without an exorbitant increase in the minute-volume of breathing. There is also a greater capillary diffusion area of the lungs, which means that a greater amount of blood can be aerated in a given time and thus foster economy.

94. Circulatory changes.—*a.* Circulation of the blood through the tissues supplies oxygen and nutriments to them and removes from them lactic acid, carbon dioxide, and other wastes. Circulation of the blood is often a limiting factor in the ability of an individual to respond to requirements of physical exertion. A period of physical training improves the ability to increase the minute volume of blood flow and renders the heart more efficient.

b. It has been shown that certain champion Olympic swimmers gave a mean basal pulse rate of 47.5, with a range from 40 to 52. In general, it was found that the length of athletic experience influenced the degree of pulse retardation. Another observation showed that training slowed the resting pulse as much as nine beats per minute and that this especially influenced the noon and afternoon pulse. It was also observed that even with acute infections the heart rates of trained men were increased less than those of the untrained. Therefore, "In strong athletes the pulse rates are 10 to 20 or even 30 beats slower than in men of sedentary habits."

c. The conclusion drawn from the action of the pulse is that regular training exercise brings about a marked increase in the tone of the

vagus center in the brain and that this makes itself evident in the slow pulse of the athlete.

d. Given the same task to perform, the trained man begins with the greater advantage of a slower heart rate; but on the whole, his heart accelerates as many beats in response to the task as does the heart of the untrained subject. Investigation has shown that the average increase in the pulse frequency was 103 percent for nonathletes and 104 percent for athletes. However, the former began with average resting pulse rates of 81, while the latter had average resting rates of 66. Although the pulse rate of the athlete is slower during a period of work, his relative percentage acceleration shows a larger response than does the nonathlete.

e. Regarding the cardiac output during exertion, the fundamental difference between the trained and untrained man is that the heart of the trained man pumps more blood per minute with fewer strokes than does that of the untrained man. Schneider in his researches observed that one outstanding athlete doubled his pulse rate with a load of work that required 2,000 cc. of oxygen, while an untrained man did not quite double his rate with the same load. He says, "Doubling the pulse rate of the athlete means roughly an increase from 60 to 120, while doubling it in the nonathlete means an increase from 80 to 160 or from 90 to 180. A pulse rate of 120 during work is associated in no sense with strain; but one of 180, as in the man out of training, is near the extreme upper limit of efficiency for the heart. It has been maintained for some time that the efficiency of the heart begins to progressively fall off at rates between 160 and 180 beats per minute. With the high rates of the heart, diastole becomes too brief to allow the ventricles to relax and refill completely."

f. Since the athlete has a stronger heart it empties itself more completely at each beat. This means that for a given venous pressure the output per beat is larger in the trained than the untrained man. Given a larger stroke per beat and a slow pulse rate, the athlete is enabled to transport oxygen more readily.

g. Physical conditioning is recognized by the time required for the pulse rate to return to normal after exercise. The athlete shows a rapid return and possibly a subnormal reaction; the inefficient man is slow in his return to a normal rate.

h. The determination of the arterial blood pressure of persons at rest does not offer much of value in estimating their true physical condition. Investigators have shown that training does not affect striking nor constant changes on resting blood pressure. However, regular physical exercise tends to keep the diastolic pressure at a lower level by reducing

the peripheral resistance. Furthermore it reduces the height to which the systemic arterial pressure rises during work.

i. The opinions of today regarding the heart in exercise are summed up as follows: carefully graduated exercise improves the nutritive condition and develops the muscular power of the heart at the same time it develops the skeletal muscles. The weight of the heart is directly related to the general development of the body musculature and is an expression of the work performed just as is the development of the body musculature. When a heart functions well it has a highly efficient coronary circulation. Observers believe that with better functioning there is either a formation of new capillaries or the opening up of hitherto unused capillaries. These various changes allow the heart of the trained man to empty itself more completely than the weaker heart of the untrained man.

j. Experiments have been made to show that in sedentary animals the red bone marrow becomes weakened and atrophied through disuse to the point where it cannot supply the red cells as rapidly as they are destroyed when the animal is later exercised. With systematic training the red cell producing tissue developed so that it was enabled to meet the demands made upon it by the hastened destruction of physical exercise. During the period of training there was a definite increase in the percentage of reticulated cells in the circulating blood. Research on athletes has also shown that regular exercise is a very important factor in the maintenance of an efficient red corpuscle forming apparatus. When an individual is active the balance between blood formation and blood destruction is kept practically on a constant level. There is some question as to whether or not there is an increase in the hemoglobin and red cell count of the blood during training. If this increase does exist, it would augment the oxygen carrying capacity of the blood and be of value especially during vigorous exertion. Some men during training have shown a gradual increase (one 3.6 percent, another 9.4 percent) in hemoglobin, while some showed no change. In two groups of experienced and inexperienced rowers, the former showed a higher cell count before a period of training than did the latter. After training 58 to 59 percent of both groups had an increased red cell count, and most of the others had a decrease. It may be that the decrease was due to overtraining.

95. Physical fitness.—In a general sense physical fitness infers good health. The healthy individual is able to combat adverse influences and to react to the conditions of his external environment and of his work in such a manner that the physiologic processes of his body

do not lose their nicety of adjustment and do not profoundly disturb or modify his internal environment.

a. Sources.—Man is born into the world with a body equipment which registers his basic capacities and abilities to meet the problems of life. This equipment may be mediocre, average, or great, but its eventful service to him will depend on how well he builds upon it and utilizes the combination of his inborn and acquired resources. This equipment may be divided into three main categories; the morphologic, physiologic, and psychologic. The morphologic is made up of the physical form and structure of the body and is largely determined by heredity. The physiologic is the basis upon which capacity for activity is enlarged and nicety of adjustment obtained by means of graded and frequent use of the organs. The psychologic is the realm of the mind which, as master of the machine, acquires greater capacity and a better equilibrium and adjustment with progressive and appropriate use. In proportion, as these three categories are properly developed and maintained, there is created a preparedness for activity and a relative freedom from fatigue. When these conditions obtain, there is good health of some degree or other. Interest in physical fitness and health goes deep enough to help avoid illness and postpone death. It has been said that the ideal goal is to be sufficiently fit to accomplish each day's work with a minimum of fatigue and to remain active to old age. This satisfactory attitude toward life will naturally be predicated upon the inborn and acquired equipment of the individual. There are some who will be compelled to train for heavy physical work to attain their goal while others will reach it better by choosing light sedentary work. Whatever the individual necessity may be, life should be so ordered that the body maintains its normal physiologic status. When there is failure to do this, pathologic conditions result, and the body becomes unhealthy. "A low degree of health or fitness seems inadvisable as it leaves no margin of safety for the experiences of adversity which so frequently descend upon mankind."

b. Criteria.—(1) Four criteria of fitness are listed as follows:

(*a*) The chemical processes of the body shall proceed in a rapid, orderly, and economical manner. This means that the digestion should not be delayed, absorbed food should be quickly utilized to form protoplasm or to yield energy, oxygen supply should be adequate for the demands of periods of work as well as rest, and elimination of excretory products should be prompt and complete.

(*b*) The structure, quality, and power of the organs should be adequate to the body's needs. Voluntary and involuntary muscles

should possess size, toughness, and contractile power sufficient for both ordinary and extraordinary demands; the heart should be able effectively to resist raised blood pressure and to circulate an adequate supply of blood; the vasomotor response of the blood vessels should be good; and the capillary bed should be capacious.

(*c*) Accurate and delicate response by the organs of special sense.

(*d*) The skillful working of the central nervous system.

(2) These criteria lead to the assumption that the important thing in physical training is not the development of big muscles and athletic prowess, but the attainment of physical and mental well-being for the purpose of proper cell activity and the elimination of wastes.

(3) The aids which bring this about are the proper selection of diet, rest, and exercise. In daily environment and occupations there are many factors which may tend to counteract this "proper selection" and reduce vitality. Therefore, should such detrimental influences arise, a well-selected course of physical training will go far in offsetting them.

c. Physical fitness in the pilot.—(1) Physical efficiency in the pilot is of great importance. His task is a hazardous one and demands alertness, keen judgment, good coordination, and quick reactions. It is only by the maintenance of good health that he is able to apply himself properly, especially as a military aviator.

(2) The military pilot is selected with great care. There is probably no comparable group of young men who begin their training with such excellent physical background. The requirements are so rigid that during the year 1935 only 450 out of 1,874 of the men examined were selected for training at the Air Corps Primary Flying School.

(3) The military pilot begins his career with a high standard of equipment and every facility is offered him to maintain it at that level. His environment is very satisfactory, his work not too fatiguing, his financial return sufficient, his opportunities for recreation and exercise splendid, his physical examinations regular and frequent. When he is ill, he has proper care and during his whole career, whether ill or in good health, he is observed closely.

(4) The pilot knows and appreciates the fact that he must keep himself in good physical trim because the length of his service in flying depends upon it. As the flight surgeon reviews every 6 months or oftener the physical condition of all pilots, he has learned to value the care and interest the pilot displays in his own well-being. Almost without exception the physical returns from examination to

examination are exceptionally good, if the bodily changes which occur with the years may be discounted.

(5) One of the features worthy of note at the Air Corps flying schools is the improved physical condition of young men (20 to 26 years) from civilian life, who, under the regime of training, care, and discipline show gains in weight, decreased pulse rates, more alertness and self-assurance, firmer muscles, better skin tonus, and increased general vigor denoting physical and mental well-being.

(6) There is a test devised by Schneider called the "Schneider Index Rating," which is used routinely with all physical examinations for flying. It is essentially a test for physical fitness and depends on the response of the cardiovascular system (by means of pulse and blood pressure readings) to postural changes and to exercise. The rating itself is judged by the use of an arbitrary index which gives a comparative indication of the functioning of the individual's neuro-circulatory apparatus and aids in determining the amount of exercise necessary for physical fitness. The Schneider test, used in conjunction with the neurological, psychic, and circulatory observations, has been very helpful in the determination of vasomotor stabilities and instabilities and everything that they imply. The procedure for performing this test is found in AR 40-110.

APPENDIX

BIBLIOGRAPHY

This manual makes no claim to originality except in arrangement and the addition of fresh material. Various textbooks, monographs, and articles have been consulted, and references drawn freely from them. Due credit must be given to the following sources which have been especially helpful in the preparation of this text:

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INDEX

INDEX

INDEX

INDEX

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